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KINESIOLOGY

and

APPLIED ANATOMY

The Science of Human Movement

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Preface

This book, based upon Henry A Stone's revision of Wilbur Pardon Bowen's *Applied Anatomy and Kinesiology*, would have been the 8th edition of Bowen's classic, were it not that marked advances in basic source fields required such extensive rewriting as to constitute in fact a new work Among these new sources are most notably data obtained from electromyography and other electronic techniques, physical medicine and rehabilitation, especially the extensive clinical investigations associated with post polio therapy and the rehabilitation of war disabilities, and the continued research in pure and applied anatomy and physiology

The book is designed to serve three broad areas of interest—athletics physical education, and physical medicine and rehabilitation For athletic coaches and trainers, for adapted physical education teachers, and for teachers of motor skills it provides a thorough and up to date factual background, with extensive illustrative applications to particular practical situations For medical and paramedical personnel engaged in physical medicine and rehabilitation it supplements the existing highly specialized pathology-centered texts by its extensive analysis of the common activities of daily life, work and sports It provides corrective, physical occupational and recreational therapists with an extensive analysis of normal functioning, to which all therapeutic programs must ultimately refer, together with introductory implications for clinical applications

Although we have recognized the pedagogical needs of beginning students no attempt has been made to oversimplify the subject matter by omitting difficult material or basic factual data necessary to develop an extensive professional knowledge of the field covered Where it has not been appropriate to go beyond the limits of an introductory textbook, references have been cited in order to guide students into the more advanced areas of research and specialized application

We are grateful to the authors and publishers who have granted permission to reproduce their material, the sources of which have been acknowledged in the text Particular mention should be made of William R Pierson, Ph D, F A C S M who took some of the photographs, Marion E Yandell, B A, who posed for some of the illustrations, Miss Patricia Douglas who supplied several original drawings and Mrs Audrey Arellanes who typed the manuscript

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Chapter 1

The History of Kinesiology*

The term kinesiology is a combination of two Greek verbs, "kinein," meaning "to move," and "logos," "to discourse." Kinesiologists—those who discourse on movement—in effect combine anatomy, the science of structure of the body, with physiology, the science of function of the body, to produce kinesiology, the science of movement of the body.

The title "Father of Kinesiology" is usually given to Aristotle (384–322 B.C.), whose treatises *Parts of Animals*, *Movement of Animals*, and *Progression of Animals*, described for the first time the actions of the muscles and subjected them to geometrical analysis. He recorded such practical observations as the following:

> the animal that moves makes its change of position by pressing against that which is beneath it. . . . Hence athletes jump farther if they have weights in their hands than if they have not, and runners run faster if they swing their arms, for in the extension of the arms there is a kind of leaning upon the hands and wrists.[1]

Aristotle was the first to analyze and describe the complex process of walking, in which rotatory motion is transformed into translatory motion. His discussion of the problems of pushing a boat under various conditions was in essence a precursor of Newton's three laws of motion. For his time, Aristotle demonstrated a remarkable understanding of the role of the center of gravity, the laws of motion, and of leverage.

Another Greek, Archimedes (287–212 B.C.), is credited with having determined hydrostatic principles governing floating bodies which are still accepted as valid in the kinesiology of swimming.[2] Some of them are now being

* This material originally appeared in slightly different form in the *Journal of the American Osteopathic Association* under the title "Notes Toward a History of Kinesiology," *58*: 572–574, May 1958; *58*: 641–644, June 1958; and *58*: 713–715, July 1958. Where possible, citations are usually to an edition which the student may readily secure rather than to the original edition. In the cases of prolific authors, only the item most important or most typical of their work is cited.

spongy material through which flow animal spirits (*succus nerveus*, sometimes translated 'nerve gas'), that agitation of these spirits from the periphery to the brain produces sensation, and that agitation from the brain produces filling and enlargement of the porosities of the muscles, with resultant turgescence. Reaction of these spirits with a substance in the muscles themselves, said Borelli, initiated a process resembling fermentation with subsequent contraction.[8] He distinguished between tonic and voluntary contractions and perhaps even vaguely perceived the principle of reciprocal innervation of antagonistic muscles. Steindler has praised him as "the real founder of modern kinetics" and as "the father of modern biomechanics of the locomotor system."[9] Singer credited him with having effectively founded and developed that branch of physiology which relates muscular movement to mechanical principles.[10]

Borelli is also regarded as the founder of the iatrophysical school of medicine, which affirmed that the phenomena of life and death are based on the laws of physics. The tenets of this school were supported by Giorgio Baglivi (1668–1706) who in 1700 published *De Motu Musculorum*, which differentiated for the first time between smooth muscles designed for long sustained efforts and striated muscles, designed for quick movements. Eventually, however the iatrophysicists' neglect of the rapidly advancing science of chemistry caused their school to fall into disrepute and to disappear.

Borelli's theory of muscular contraction was attacked almost immediately. Among his critics was Francis Glisson (1597–1677), who contended that the muscle fibers contract, rather than expand, during flexion as demonstrated by plethysmographic experiments. He suggested also that all viable tissue possesses the capacity to react to stimuli. This capacity he referred to as 'irritability.' Glisson's concept was later elaborated by Albrecht von Haller (1708–1777), the outstanding physiologist of the Eighteenth Century, into the theory that contractility is an innate property of muscle which exists independently of nervous influence.

Although the circulation of the blood through the body was first demonstrated by William Harvey, he erroneously attributed to the heart the function of recharging the blood with heat and "vital spirit."[11] Subsequently, in 1664 Niels Stensen made the then sensational declaration that the heart was merely a muscle not the seat of "natural warmth" nor of "vital spirit." This has been acclaimed as the greatest advance in our knowledge of the circulatory system since Harvey's discovery.[12] Three years later Stensen, who has been credited with laying the foundation of muscular mechanics, wrote *Elementorum Myologiae Specimen*, an "epoch making" book on muscular function. In this he asserted that a muscle is essentially a collection of motor fibers, that in composition the center of a muscle differs from the ends (tendons) and is the only part which contracts. Contraction of a muscle, wrote Stensen, is merely the shortening of its individual fibers and is not produced by an increase or loss of substance.[13]

The word "orthopedics" was coined by Nicholas Andre (1658–1742) from the Greek roots "orthos," meaning straight, and "pais," meaning 'child.' It was the opinion of this author that skeletal deformities result from muscular imbalances during childhood. In his treatise *Orthopedics or the Art of Preventing and Correcting in Infants Deformities of the Body*, published in 1741,

he defined the term "orthopedist" as a physician who prescribes corrective exercise Although this is not the modern definition of the term, Andre is recognized as the creator of both the word and the science [14] His theories were directly antecedent to the development of the Swedish system of gymnastics by Par Henrik Ling

In *Principia Mathematica Philosophiae Naturalis* which is 'perhaps the most powerful and original piece of scientific reasoning ever published [15] Isaac Newton (1642–1727) laid the foundation of modern dynamics Particularly important to the future of kinesiology was his formulation of the three laws of rest and movement which express the relationships between forces (interactions) and their effects

I Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it (This is sometimes known as the Law of Inertia and was originally proposed by Galileo in 1638)

II The change of motion is proportional to the motive force impressed, and made in the direction of the right line in which that force is impressed (Law of Momentum)

III To every action there is always opposed an equal reaction, or the mutual actions of two bodies upon each other are always equal and directed to the contrary parts (Law of Interaction) [16]

The application of these laws to muscular function may be demonstrated by the following analogy While he is pivoting a discus thrower must grasp the discus firmly (exert centripetal force) to prevent it from flying out of his hand In accordance with the Third Law the missile exerts an equal and opposite reaction (centrifugal force) When his grip is released and centripetal force no longer interacts with the discus the implement flies off in a straight line tangential to its former circular path The distance covered by the missile is proportional to the motive force imparted to it in accordance with the Second Law The trajectory of the missile is affected by gravity wind velocity and other forces tending to alter its state of uniform motion, as predicted by the First Law

According to the Newtonian world view, changes of motion are considered as a measure of the force which produces them From this theory originated the idea of measuring force by the product of mass and acceleration a concept which plays a fundamental role in kinetics The greater the speed with which the discus thrower whirls the greater the acceleration applied to the mass of the discus, the farther it will fly before gravity returns it to earth and the greater the force said to have been applied to the discus

Newton is also credited with the first correct general statement of the parallelogram of force based on his observation that a moving body affected by two independent forces acting simultaneously moved along a diagonal equal to the vector sum of the forces acting independently By further analysis of the laws of movement as applied by the discus thrower it can be demonstrated mathematically that the horizontal and vertical forces acting on the flying discus are equal The diagonal which is equal to the vector sum of the horizontal and vertical forces is therefore 45 degrees and the missile should traverse the greatest distance when it travels at this angle In actual practice of course other factors of lift drag shape gyroscopic rotation and so forth

enter the situation and it is possible that the most effective angle of release may not always be the one which is the theoretical optimum [17] However, since two or more muscles may pull on a common point of insertion, each at a different angle and with a different force, the resolution of vectors of this type is a matter of considerable importance in the solution of academic problems in kinesiology

Within the past few years physicists have demonstrated that Newton's theories are valid only within the frame of reference in which they were conceived, they do not apply to relationships between forces in the Einsteinian world view This discovery has little significance for the kinesiologist however, since he deals primarily with the forces of gross muscular movement and these are governed by the laws of motion set forth by Newton

In his studies of muscular contraction James Keill (1674–1719) calculated the number of fibers in certain muscles assumed that on contraction each fiber became spherical and thus shortened, and from this deduced the amount of tension developed by each fiber to lift a given weight In *An Account of Animal Secretion the Amount of Blood in the Human Body, and Muscular Motion* (1708) Keill drew the erroneous conclusion that a muscle could not contract to less than two thirds of its greatest length [13]

In *An Essay on the Vital and Other Involuntary Motions of Animals* published in 1751, Robert Whytt (1714–1766) rejected Baglivi s theory of muscular action and contended that movement originates from an unconscious sentient stimulus This brought him into disagreement with von Haller Possibly Whytt may not have comprehended the principle that movement may originate as reflex action to external stimuli, however it appears that he was cognizant of the stretch reflex and the fact that a given stimulus may be adequate to excite one nerve ending but not another Their differences of opinion arose from the fact that von Haller thought in terms of isolated muscle, Whytt in terms of the reflex control of the movements of an organism [13]

The subject of anatomy, as taught prior to the time of Marie François Xavier Bichat (1771–1802) consisted of little more than dogmatic statements handed down through the ages Through his efforts anatomy became a science solidly founded on the systematic observation of and experimentation with the various systems into which he divided the living organism Bichat observed that the organs of the body are composed of individual tissues with distinctive characteristics, and was the first to describe the synovial membranes [18] He is regarded as the author of the modern concept of structure as the basis of function, which led to the development of rational physiology and pathology [19]

The six Croonian Lectures on Muscle Motion* delivered by John Hunter (1728–1793) in 1776 1777, 1779 1780 1781 and 1782 [20] brought together all of this great anatomist s observations concerning the structure and power of muscles and the stimuli by which they are excited Muscle, he declared, while

* William Croone a professor at Gresham College England who died in 1684 left in his will a plan for annual lectures on the physiology of muscular motion Fulton commented It is literally true that the history of muscle physiology in the Eighteenth Nineteenth and Twentieth Centuries has been largely developed at these annual lectures (*Muscular Contraction and the Reflex Control of Movement* pp 15–16)

it is endowed with life is fitted for self motion and is the only part of the body so fitted He emphasized that muscular function could be studied only by observations of living persons, not cadavers In his lecture series Hunter described muscular function in considerable detail including the origin, insertion, and shape of muscles, the mechanical arrangement of their fibers, the two joint problem, contraction and relaxation, strength hypertrophy, and many other aspects of the subject His lectures may be regarded as summarizing all that was known about kinesiology at the end of the Eighteenth Century, when unwittingly, kinesiologists stood at the threshold of a discovery which was to revolutionize their methods of investigation

About 1740 physiologists became excited over the phenomena produced by electrical stimulation of muscles Haller summarized many of the early experiments in his treatise on muscle irritability and Whytt reported clinical observations on a patient treated by electrotherapy Animal electricity was proposed as a substitute for the animal spirits which earlier investigators had believed to be the activating force in muscular movement During the summer of 1786 Luigi Galvani (1737–1798) studied the effects of atmospheric electricity upon dissected frog muscles He observed that the muscles of a frog sometimes contracted when touched by a scalpel, which led him to the conclusion that there was indwelling electricity in animals and that the movement of a muscle was the result of its exterior negative charge uniting with the positive electricity which proceeded along the nerve In a violent attack on this theory, Allessandro Volta (1745–1827) contended that activation actually resulted from the contact of dissimilar metals Galvani riposted with a second paper, in which he reported that he had produced muscular contraction without the intervention of metals by bringing the vertebral column of a prepared frog into contact with a thigh muscle It is now known that this phenomenon results from the difference in potential (injury current) which exists between an excised frog nerve and a severed muscle [21]

The study of animal electricity at once became the absorbing interest of the physiological world The greatest name among the early students of the subject was that of Emil DuBois Reymond (1818–1896) who laid the foundations of modern electrophysiology

Fascinated by the prospect of investigating muscular response produced by electrical stimulation Guillaume Benjamin Amand Duchenne (1806–1875) set out to classify the functions of individual muscles in relation to body movements although he recognized that isolated muscular action does not exist in nature [22] His masterwork *Physiologie des mouvements* appeared in 1865 and has been acclaimed one of the greatest books of all times [23] Unfortunately this classic was not translated into English until 1949 and then appeared in only a small edition As a result it is not generally available for reference work

The modern concept of locomotion originated with the studies of Borelli however, very little was accomplished in this field prior to the publication of *Die Mechanik der menschlichen Gerverkzeuge* by the Webers in 1836 Their treatise which still stands as the classical work accomplished by purely observational methods firmly established the mechanism of muscular action on a scientific basis The Weber brothers Ernst Heinrich (1795–1878) Wilhelm Eduard (1804–1891) and Eduard Friedrich Wilhelm (1806–1871) be

lieved that the body was maintained in the erect position primarily by tension of the ligaments, with little or no muscular exertion that in walking or running the forward motion of the limb is a pendulum swing due to gravity and that walking is a movement of falling forward, arrested by the weight of the body thrown on the limb as it is advanced forward The Webers were the first to investigate the reduction in the length of an individual muscle during con

FIG 1 —Guillaume Benjamin Amand Duchenne de Boulogne investigating the effect of electrical stimulation of the left frontalis muscle (Jokl and Reich courtesy of J Assoc Phys & Ment Rehab)

traction and devoted much study to the role of bones as mechanical levers They were also the first to describe in chronological detail the movements of the center of gravity [24]

The study of animal mechanics was expanded by the talented and versatile Samuel Haughton (1821–1897) in numerous papers bearing such titles as *Outlines of a New Theory of Muscular Action* (1863) *The Muscular Mechanism of the Leg of the Ostrich* (1865) *On Hanging Considered from a Mechanical and Physiological Point of View* (1868) and *Notes on Animal Mechanics*

(1861–1865) However, advancement of knowledge concerning body mechanics was greatly impeded by lack of a satisfactory method of chronological reproduction of movement This advance was made when Janssen, an astronomer who had utilized serial pictures in 1878 to study the transit of Venus suggested kinematographic pictures to study human motion Eadweard Muybridge (1831–1904) produced his book *The Horse in Motion* in 1882, and his monumental *Animal Locomotion* in eleven volumes in 1887 an abridgement of which was reissued in 1955 under the title of *The Human Figure in Motion* [25] Etienne Jules Marey (1830–1904) who was convinced that movement is the most important of human functions and that all other functions are concerned with its accomplishment, described graphic and photographic methods for biological research in *Du mouvement dans les functions de la vie* (1892) and *Le mouvement* (1894)

These photographic techniques opened the way for the experimental studies of Christian Wilhelm Braune (1831–1892) and Otto Fischer (1861–1917), which today ' dominate the study of the human gait ' [26] Even more famous than these investigations was their report of an experimental method of determining the center of gravity published in 1889 Its essence has been presented in an article by Hirt Fries and Hellebrandt [27] According to these authors the major premise of Braune and Fischer was that a knowledge of the position of the center of gravity of the human body and its component parts was fundamental to an understanding of the resistive forces which the muscles must overcome during movement Their observations were made on four cadavers, which after having been preserved by freezing were nailed to a wall by means of long steel spits The planes of the centers of gravity of the longitudinal, sagittal and frontal axes were thus determined By dissecting the bodies by means of a saw and locating the points of intersection of the three planes they were able to establish the center of gravity of the body The center of gravity of the component parts was determined in the same manner Because one cadaver began to decompose and the investigators were not permitted to dissect a second cadaver complete observations were made on only two of the four bodies When the centers of gravity were plotted on a life size drawing of one of the cadavers and compared photographically with those of a soldier having similar body measurements the investigators observed a remarkable similarity Braune and Fischer concluded that the original position of their frozen cadavers could be considered a normal one and referred to it as normalstellung which was intended to indicate only that it was the standard position in which their measurements were taken Unfortunately this term came to be understood as the ideal position and generations of students were exhorted to imitate it

On the basis of subsequent studies, Rudolf A Fick (1866–1939) concluded that the theory of normalstellung was not entirely valid as the recumbent position of a cadaver could not be transferred to the vertical stance The degree of lumbar lordosis is much less when the body is recumbent than when vertical in the latter position the center of gravity shifts forward considerably more than Braune and Fischer assumed Fick contended that when peoples of different races and cultures are considered there is no one posture that is normal for all Recent anthropological investigations have confirmed his opinion [28] Fick concerned himself with nearly every aspect of body mechan

ies and remains the leading authority on the mechanics of articular movement His work on the mechanics of articular and muscular movement is considered by authorities to be an indispensable guide for students of kinetics [9] Unfortunately, his masterworks *Handbuch d Anatomie und Mechanik der Gelenke* and *Spezielle Gelenk und Muskelmechanik*, each of which comprises several volumes, have not been translated into English and remain largely inaccessible to those who do not read German This is also true of the works of Hans Strasser (1852-1927), whose four volume *Lehrbuch der Muskel und Gelenkmechanik* remains untranslated

The late Nineteenth and early Twentieth Centuries were most productive of physiological studies closely related to kinesiology Adolf Eugen Fick (1829-1901) made important contributions to our knowledge of the mechanics of muscular movement and energetics and introduced the terms isometric and isotonic The study of developmental mechanics was introduced by Wilhelm Roux (1850-1924) who stated that muscular hypertrophy develops only after a muscle is forced to work intensively, a point of view which was later demonstrated experimentally by W Siebert B Morpurgo showed that increased strength and hypertrophy are a result of an increase in the diameter of the individual fibers of a muscle, not a result of an increase in the number of fibers [29] The theory of progressive resistance exercise is based principally on the studies of Morpurgo and Siebert

John Hughlings Jackson (1834-1911), a neurologist made definite contributions to knowledge pertaining to the control of muscular movement by the brain His conclusions* are summed up in these words

> the motor centres of every level represent movements of muscles, not muscles in their individual character the distinction between muscles and movements of muscles is exceedingly important all over the field of neurology
>
> The occurrence of convulsion of a muscular region which is already imperfectly and yet permanently paralyzed is unintelligible without that distinction And without it we shall not understand how it can happen that there is loss of some movements of a muscular region without obvious disability in that region [30]

Jackson mentioned post epileptiform aphasia and hemiplegia as practical examples of his dictum His ideas were cited approvingly by Charles Edward Beevor (1854-1908) in his 1903 Croonian Lecture on Muscular Movements [31] The aphorism nervous centers know nothing of muscles they only know of movements, which has frequently been attributed to Beevor should be credited to Jackson

Beevor himself pointed out that the technique of utilizing electrical stimulation employed by Duchenne demonstrated what a muscle *may* do, not what it *does* do, and since only the stimulated muscle responds this method fails to show the action of associated muscles which may often or always contract simultaneously in the natural situation, and this may modify the resultant movement He referred to James Benignus Winslow s previous objection to the use of cadavers to demonstrate muscular action and the fallacious conclusions which had been based on these observations After careful study of the muscular actions involved in the movements of certain joints, Beevor

* Quoted by permission

(1861–1865). However, advancement of knowledge concerning body mechanics was greatly impeded by lack of a satisfactory method of chronological *reproduction of movement*. This advance was made when Janssen, an astronomer who had utilized serial pictures in 1878 to study the transit of Venus, suggested kinematographic pictures to study human motion. Eadweard Muybridge (1831–1904) produced his book *The Horse in Motion* in 1882, and his monumental *Animal Locomotion* in eleven volumes, in 1887, an abridgement of which was reissued in 1955 under the title of *The Human Figure in Motion*.[25] Etienne Jules Marey (1830–1904), who was convinced that movement is the most important of human functions and that all other functions are concerned with its accomplishment, described graphic and photographic methods for biological research in *Du mouvement dans les functions de la vie* (1892) and *Le mouvement* (1894).

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could be ignored in his analysis In endeavoring to draw practical applications from his theoretical studies, Koch commented that alterations in posture increase the stress in certain regions and decrease it in others and that if postural alterations are maintained the inner structure of the affected bones is altered The proper mechanical means of counteracting these alterations, said Koch, was to impose new mechanical conditions by the use of braces, jackets or other suitable devices to reverse the transformative process and restore the original structure

Murk Jansen s monograph *On Bone Formation* (1920) disagreed with many of Wolff s premises, including the "dualistic doctrine that bone formation is dependent on both tension and pressure Wolff s hypothesis that these forces intersect at right angles in the trabeculae of cancellous bone constituted a fatal flaw in the theory, contended Jansen since the major trabecular systems do not always cross at right angles Jansen reputedly insisted that the jerking action of a contracting muscle, combined with gravity, is the chief mechanical stimulus for the formation of bone, and, moreover, is a determinative factor in the structure of cancellous bone [35, 36]

Eben J Carey[37] also criticized Koch s denial of the role of muscular tension in the formation of bone and asserted that the powerful back pressure vectors produced by the forces of muscular contraction are the dominant factors affecting the growth and structure of bone He rejected Koch s emphasis on static pressure The body, he said is sustained in the upright posture by mutual interaction between the skeleton and the muscles, and he expressed the opinion that the dynamic action of the muscles may exceed the static pressure of body weight He contended that the normal growth and structure of mature bone is the result of this dynamic muscular activity and the intrinsic capacity of skeletal cells to proliferate centrifugally against extrinsic centripetal resistances

F Pauwels endeavored to demonstrate that muscles and ligaments act as traction braces to reduce the magnitude of stress in the bones His work was criticized by Evans on the grounds that it was concerned only with the stresses produced by loads placed on solid models shaped like bones Discussing the validity of the various theories Evans concluded that a decision must await experimental evidence It is possible that Wolff and Roux overemphasized the importance of mechanical stresses without proper consideration for biological factors which sometimes exceed mechanical influences Nevertheless the theory of functional adaptation to static stress remains a major hypothesis in the study of skeletal development

Prior even to the time when the development of bone became a subject of heated debate, yet more highly controversial hypotheses were introduced into the scientific world Charles Darwin (1809–1882) published two books *The Origin of the Species* (1859) and *The Descent of Man* (1871), which have since become classics and have revolutionized man s ideas concerning the human body [38] His conception of man as a 'modified descendant of some preexisting form whose framework is constructed on the same model as that of other mammals and whose body contains both rudimentary muscles which serve useful functions in the lower mammals and modified structures which resulted from a gradual change from quadrupedal to bipedal posture was at first bitterly opposed Now generally accepted, his concepts have clarified

proposed that the muscles be classified as prime movers, synergic muscles, fixators, or antagonists He was of the opinion that the antagonistic muscles always relaxed in strong resistive movements

In this respect Beevor was influenced by the work of Charles Sherrington (1857–1952), who proposed the theory of the reciprocal innervation of antagonistic muscles in a number of papers published near the end of the Nineteenth Century and later incorporated into his book *The Integrative Action of the Nervous System* (1906) a monumental work in the history of kinesiology which has since been republished many times Contemporaneously, Henry Pickering Bowditch (1814–1911) demonstrated the treppe phenomenon (1871) the all or none principle of contraction (1871), and the indefatigability of the nerves (1890) The Sherrington theory and the all or none principle are considered fundamental for an understanding of kinetic events in the human body [32] Of inestimable moral value to kinesiologists, who at that time were insecure in their profession and depressed by the jibes of critics who contended that the study of the body was unworthy of man, was Sherrington s insistence that the importance of muscular contraction to us can be stated by saying that all man can do is to move things, and his muscular contraction is his sole means thereto [33]

Karl Culmann (1821–1881) a German engineer, reviewed in *Die Graphische Statik* all that had been accomplished up to 1865 in the solution of static problems by graphic methods Speaking at a meeting of scientists in 1866, he called attention to the fact that when the calcium phosphate was dissolved from the upper end of the femur the internal architecture of this bone coincided with graphostatic determinations of the lines of maximum internal stress in a Fairbairn crane, which he assumed resembled the femur in shape and loading Although his basic assumption has been severely criticized, his analysis forms the basis of the trajectorial theory of the architecture of bones (See p 39)

The trajectorial theory was supported by Roux and became the basis for his interpretation of the trajectory system of other bones In 1892 this theory was classically expressed by Julius Wolff (1836–1902) in the famous Wolff s Law Every change in the form and function of a bone or of their function alone is followed by certain definite changes in their internal architecture, and equally definite secondary alteration in their external conformation in accordance with mathematical laws He believed that the formation of bone results both from the force of muscular tensions and from resultant static stresses of maintaining the body in the erect position and that these forces always intersect at right angles

In his paper on the Laws of Bone Architecture [34] which has been proclaimed the most thorough study of stress and strain in a bone by mathematical analysis of cross sections [35] Koch concluded that the compact and spongy materials of bone are so composed as to produce maximum strength with a minimum of material and that in form and structure bones are designed to resist in the most economical manner the maximum compressive stresses normally produced by the body weight Because the stresses from body weight are so much greater than the tensions which are normally produced by the muscles reasoned Koch the effect of muscular action is of relatively little importance in determining the architecture of the bones and therefore,

with their legs spread apart An impact on a person sitting with the knees or legs crossed tends to drive the head of the femur out of the acetabulum but a similar impact on an individual sitting with his legs apart tends to drive the head of the femur further into the acetabulum until the femur buckles and breaks [54]

As early as 1880 Wedenski demonstrated the existence of action currents in human muscles, although practical use of this discovery had to await the invention of a more sensitive instrument This became available when W Einthoven developed the string galvanometer in 1906 The physiological aspects of electromyography were first discussed in a paper by H Piper, of Germany, in 1910-1912, however, interest in the subject did not become wide spread in the English speaking countries until publication of a report by E D Adrian in 1925 [55] By utilizing electromyographic techniques Adrian demon strated for the first time that it was possible to determine the amount of activity in the human muscles at any stage of a movement The development of the electromyograph represents one of the greatest advances in kinesiology By means of this instrument many generally accepted concepts of muscle action have been proved erroneous and new theories have been brought forth The use of the electromyograph has become so widespread that it is not pos sible to cite even the principal students who have employed it

In the study of the physiologic aspects of striated muscular activity how-ever, one name stands preeminent The brilliant studies of Archibald Hill[56] unquestionably distinguish him as the world s leading authority in this field

Interest in the subject of posture has declined among kinesiologists in the United States during the last few years In part, this may have resulted from general acceptance of the dictum that the physiological benefits obtained from correction of common postural defects are mostly imaginary, [57] in part, it may reflect the growing realization that individual differences almost pre clude valid generalizations Perhaps much of the effort which in earlier times was devoted to the study of static posture is now directed to research concern ing dynamic locomotion Wallace Fenn Plato Schwartz, Verne Inman Herbert Elftman Dudley Morton[58 62] and Steindler[9] should be listed among the scientists who have made important contributions to knowledge concern-ing this phase of kinesiology Laurence Morehouse and John Cooper, Mc Clurg Anderson and Thomas Cureton have made notable contributions to the study of locomotion as well as other kinesiological aspects of sports [63 65] In all probability, most coaches and trainers have not yet assimilated into their training programs all of the principles which these kinesiologists have pre sented

The use of cinematography for kinesiological studies of athletes and indus trial workers has become commonplace An important recent development in the study of human motion is the use of cineradiographic techniques In time advances in technique may make it possible to record the complete sequence of musculoskeletal movements rather than only a fraction of them A fascinating new parameter was opened up with the invention of the elec tronic stroboscope by Harold Edgerton This instrument which is capable of exposures as short as one millionth of a second can record in a series of instantaneous photographs an entire sequence of movement Although the potentialities of this apparatus for kinesiological analysis have not yet been

many questions pertaining to kinesiology which might otherwise have remained obscure and have attracted to the study of kinesiology many physical anthropologists whose contributions have been of great value Although the limitations of space do not permit inclusion of all of them Ernest Hooton, Ethel J Alpenfels, Wilbur Krogman, and N M Tappen may be cited as typical examples [39-42]

Yet another scientist of the Nineteenth Century Angelo Mosso (1848–1910) made an important contribution to the study of kinesiology, the invention of the ergograph in 1884 This instrument, now available in an endless array of specialized forms,[43-45] has become a nearly indispensable tool for the study of muscular function in the human body

The first extensive compendium on body mechanics, *The Human Motor*, by Jules Amar, was published in 1914 Inspired largely by the increase in work productivity achieved by Frederick Winslow Taylor s[46] application of scientific principles of body mechanics to industry Amar (1879–) sought to bring together in one volume all the physical and physiological elements of industrial work The book was translated into English in 1920 [47] but it is now out of print and difficult to secure Since its publication countless industrial studies based on Amar s principles have been published perhaps the best known of which are the numerous reports of the British Industrial Fatigue Research Board and of Frank B and Lillian M Gilbreth

This type of kinesiological research initiated studies in the unexplored areas of time and motion Investigations in this field have been greatly accelerated as a result of rapid advances in engineering and the development of machines so complex that the physical abilities of the human operator become a limiting factor in their use Scientists working under government auspices have brought together massive collections of data pertaining to the application of scientific principles of body mechanics to industry now known as human engineering [48-51] or the science of ergonomics— the customs, habits or laws of work It is anticipated that attempts to solve the problems of space flight will provide further impetus to studies of this nature

The insistence of Andrew Taylor Still (1828–1917) that proper structural alignment of the body is of vital importance in the maintenance of health and in the treatment of disease resulted in the development of osteopathy as a separate school of medicine and contributed significantly to the general recognition of the value of manipulation in physical medicine Colin Mackenzie s text[52] on the medical aspects of kinesiology achieved great popularity early in the present century but has now been replaced by the book by Goldthwait and his collaborators [53] However Steindler s *Kinesiology of the Human Body Under Normal and Pathological Conditions* seems destined to become the classic in this field

Knowledge of this subject is still limited as is reflected in Hooton s dictum that an adequate comprehension of bodily mechanics has not been achieved as yet [39] Nevertheless information is accumulating and some of the facts and theories which have been presented are both curious and instructive As an example it has been observed that men frequently sustain femoral fractures as a result of automobile accidents whereas women are more likely to incur dislocations of the hip This difference is attributed to the social conditioning of women to sit with their knees or legs crossed whereas men sit

According to the old psychological stimulus → response theory the individual is merely a communication channel between the input and the output. This view is not acceptable to modern psychologists who contend that its proponents failed to consider the contribution which the individual makes to the circuit. In current information theory it is recognized that through experience men accumulates certain knowledge about his external environment, as, for example how an object travels through space and that the signals he received from his kinesthetic proprioceptors reveal to him how his body is responding to the external presentation. The individual is viewed as a limited capacity channel, receiving and responding to signals originating from internal sources as well as from the external display. The relative importance of these two types of stimuli in determining individual response appears to vary with practice and with the ease or difficulty of the required response. One of the chief difficulties confronting a performer is to separate one signal from another when they are presented in rapid succession. A distinguishing characteristic of a skilled performer is his ability to select integrate and respond only to those signals which are germane to the situation that is in effect to filter out signals which are mere noise on the input circuit. The fact that stimuli may be correlated with each other may enhance the difficulty for the performer.[70]

The complexities of the mechanisms involved as well as their practical implications for kinesiologists have been revealed by extensive electroencephalographic researches. W. Grey Walter[71] tentatively advances the hypothesis that the brain functions like a fantastically gigantic electronic scanner, monitoring millions of items of sensory information and collating them with items and patterns previously stored in the memory. He sees some evidence that the master function of the brain is pattern seeking—the identification of meaningful relationships in the data under its security. Coupling such a theory with the expanding findings of cybernetics of the psychology of learning and of other fields makes it safe to predict far reaching advances in the understanding of human functioning. These new knowledges will have rich import for kinesiology.

Although extensive studies have been made concerning the nature of kinesthesis[77] the findings thus far are meager and inconclusive attempts to apply the admittedly scanty data to practical problems related to the selection for training in skilled movements have yielded suggestive rather than conclusive results.[73, 74] It has been postulated the kinesthesis is itself a complex rather than a unit perhaps one involving several loosely related functions.[74] This area presents an enormous potential for kinesiological research.

The entire trend of current developments indicates that the kinesiologist can no longer limit his scope to the mere mechanical analysis of movement, he must consider increasingly the meaning and significance of musculoskeletal movements. The human is a purposeful being and the study of mechanical principles alone will reveal only a fraction of the entire spectrum of his movements—perhaps the fraction of the least importance.

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FIG 2 —Electronic flash photograph of tennis player serving (Edgerton)

determined it seems particularly promising for analyzing the various sequences of skilled movement In a somewhat related field, the new science of aerodynamics has greatly increased our knowledge of the movement of objects in space through investigations involving the use of wind tunnels and other specialized research tools and artifically produced environments

Psychologists, psychoanalysts psychiatrists and other social scientists have become interested in investigating the psychosomatic aspects of kinesiology The studies of J H Van Den Berg Edwin Straus Temple Fay, and Norbert Weiner may be cited as representative analyses which have contributed significantly to our knowledge concerning the why of human movement 66 69

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Chapter 2

The Framework and Joints of the Body

The use of dried bones as skeletal demonstration materials frequently generates the impression that the skeleton is a hard rigid, static structure comparable to steel girders in a skyscraper One purpose of this chapter is to show that skeletal structures are dynamic, living developing growing tissues whose metabolism influences function and is influenced by function

THE COMPOSITION AND STRUCTURE OF BONES

Constituents of Bone Tissue Mature living bone is about 50 per cent water and other fluids and about 50 per cent solids Of the solids about one third is organic and about two thirds are inorganic If all organic material and water are removed the remaining structure crumbles easily On the other hand if all inorganic salts are extracted from a long bone the remaining structure, when fresh and moist can be bent easily and tied into an overhand knot After maturity the proportions of fluid and of organic material gradually decrease with age For these and other reasons, the bones of aged people are brittle and healing becomes more difficult

The organic portion of bones can be divided into (1) *cells*, which constitute only a minute fraction of the total weight of bone, (2) *fibrous matrix*, formed largely of fibrils of *collagen* a protein substance which can be extracted as glue or gelatin and (3) amorphous (formless) *ground substance*, consisting mostly of muco polysaccharides (protein sugar compounds) The ground substance may be regarded as condensed tissue fluid,[1] and along with the tissue fluid it is interspersed among the collagenous fibers All of this organic matter is impregnated with the inorganic bone salts, mostly consisting of calcium phosphate

Organization of Bone Tissue Bone tissue is sparsely permeated with blood vessels lymph channels and nerve branches The microscopic *Haversian system* is the structural basis of compact bone Most conspicuous are the cylindrical tunnels about 0 05 mm in diameter, called the *Haversian canals* or *central canals*, which are usually aligned with the long axis of the bone They branch irregularly, and contain small blood vessels lymph vessels, and

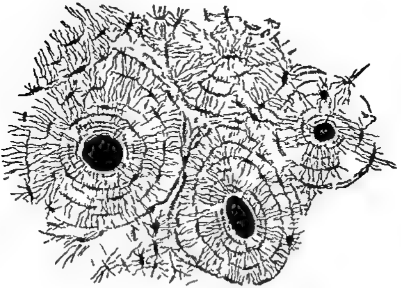

Fig 3 —Transverse section of compact tissue bone Magnified (Sharpey)

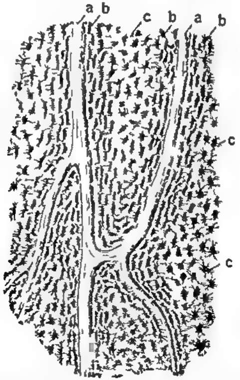

Fig 4 —Section parallel to the surface from the body of the femur × 100 *a* Haversian canals *b* lacunae seen from the side *c* others seen from the surface in lamellae which are cut horizontally (*Gray s Anatomy*)

nerve fibers Bone tissue is laid down around each Haversian canal in very thin cylindrical concentric layers known as *lamellae* Between the lamellae are found many small cavities called *lacunae* each of which contains an *osteocyte* or bone cell A lacuna is roughly cigar shaped, but is made irregular

by the exit of numerous minute channels known as *canaliculi* which communicate with other lacunae and with the Haversian canals These passageways are filled with tissue fluid

Kinds of Bones *Long bones* such as the humerus and tibia are found in the limbs *Short bones* are roughly cubical, and are represented only by the carpal and tarsal bones *Flat bones* represented by the sternum ribs, some of the skull bones, ilium, and scapula, have outer layers of compact bone with an interior of spongy bone and marrow They are designed to serve as extensive flat areas for the attachment of muscles and ligaments and except for the scapula to enclose cavities They are usually curved thick where tendons and fascia sheets attach and thin to the point of translucence where the fleshy muscle fibers attach directly to the bone *Irregular bones* such as the ischium, pubis maxilla and vertebrae are adapted to special purposes

Structure and Functions of the Long Bones Evolutionally the long bones are adapted for weight bearing and for sweeping speedy excursions They serve these purposes admirably because of their tubular form their broad and specialized articular surfaces and shapes at their ends, and their great length

The long central tubular part of a long bone is called the *shaft, body*, or *diaphysis* It contains the hollow *medullary cavity*, filled with marrow and surrounded with compact bone After maturity, the compact bone of the shaft blends gradually into the compact bone of the two *ends* The proximal end is usually called the *head* Both the proximal and distal ends typically display protusions called *condyles tubercles* or *tuberosities* which serve as attachments or pulleys for tendons and ligaments The shapes of the articular surfaces are commonly specialized to enable the bone to fit securely into the conformations of its neighbor, and to determine or limit the kind of action possible at the joint Each articular surface has a cap of hyaline cartilage This articular hyaline cartilage functions to increase the smoothness of fit prevent excess wear, absorb shocks and prevent dislocations of the joints

Toward the ends of long bones the medullary cavity gives way to *spongy* or *cancellous bone* within the external layers of compact bone Spongy bone is as hard as compact bone, but is arranged in a complex grillwork These bars of latticework are called *cancelli* or *trabeculae* (from Latin, meaning lattice bars or little beams) The basic tubular structure of long bones conserves weight, at the same time providing great resistance to stress and strain

Membranes of Bone The *periosteum* is a connective tissue which covers the outside surface of bones, except at articular surfaces where it is replaced by the articular hyaline cartilage It has two layers an outside layer of collagenous fibers and a deep layer which is osteogenic (that is capable of producing *osteoblasts* which in turn may develop into osteocytes) Periosteum is supplied with blood vessels and nerve branches It is extremely sensitive to injury and from it originates most of the pain of fractures bone bruises and shin splints It adheres to the outer surface of compact bone by sending tiny processes, similar to small roots into the bone Muscles are attached to periosteum not directly to the bone

The *endosteum* is a similar connective tissue which lines the medullary cavity and Haversian canals, and covers trabeculae of spongy bone It, too is osteogenic

FIG 5 —Frontal longitudinal mid section of the right femur (After Koch)

Bone Marrow The primary function of red bone marrow is to manufacture red blood cells, although it also has osteogenic properties. At birth red marrow fills both the medullary cavities and the intratrabecular spaces of all long bones. As spongy bone increases in amount with age, the red marrow retreats to the intratrabecular spaces, leaving the medullary cavity filled with fatty yellow marrow. By the time of puberty almost all of the marrow in limb bones is yellow, and red marrow is normally found only in parts of the ribs, skull, sternum, and vertebrae.

Effects of Bone Function upon Bone Structure Pages 26 to 27 in Chapter 1 have presented an historical account of the hypothesis that the trabeculae are formed in response to the stresses and strains of weight bearing and other functions of bone. The *trajectorial theory* of bone structure, as developed by Culmann, Wolff, and Roux, postulated that the trabeculae were laid down along lines of compressive or tensile force. Mathematical analyses were made in an attempt to show that the trabeculae did indeed follow the lines of force, and that they originated at right angles to the surface of the bone and crossed each other at right angles, as was demanded by the engineering theories and methods which were employed. Wolff's classic statement was that "Every change in the form and function of bones, or of their function alone, is followed by certain definite changes in their internal architecture, and equally definite secondary alteration in their external conformation, in accordance with mathematical laws." The theory has been attacked continuously since its proposal. An exhaustive critical review of the evidence has been made by Evans,[2] from whose book the following conclusions are adapted. *First*, the mathematical analyses which tended to support the trajectorial theory were of doubtful validity. *Second*, functional stresses undoubtedly influence bone formation and growth, but the extent and nature of this mechanism is the subject of much disagreement. *Third*, other factors, including hereditary tendencies, nutrition, biochemical influences, and vascular conditions, may have an influence equal to or greater than functional stresses.

Wolff's Law of Bone Transformation seems to have been an over-statement, especially with regard to its phrase "in accordance with mathematical law." Yet it cannot be discarded entirely. Mainland[3] cites numerous incidents demonstrating the effects of function upon bone growth, repair, and atrophy. Normal bone repair after fractures is found to be suited to the stresses received; bones atrophy or cease to develop after muscular forces are removed by paralysis; constant pressures on bone may cause atrophy, but intermittent pressures seem to result in bone growth; bone growing in tissue culture, separated from any organism, has been known to adapt itself to the artificial forces present; and inactivity resulting from encasement in plaster casts and from other causes is often followed by atrophy or cessation of growth.

GROWTH AND DEVELOPMENT OF BONES

Ossification of Bones *Ossification* means the depositing of bone salts in an organic matrix. It must be preceded by the differentiation and proliferation of cells which will lay down the collagenous matrix, and this may occur either in an existing connective tissue membrane, producing *intramembranous ossification*, or in hyaline cartilage, producing *endochrondral* or *intracartilaginous ossification*. The clavicle and most skull bones ossify intramembran

ously, the short bones intracartilaginously and the long bones by both methods

Ossification of Long Bones In the embryo hyaline cartilage models of the bones appear Well before birth a primary center of ossification known as a *diaphysis*, arises near the center of the future shaft of long bones Ossification progresses in all directions from these primary centers At the same time, a *bone collar* ossifies intramembranously in the periosteum around the shaft, defining its outside diameter One or more secondary centers of ossification called *bony epiphyses* develop at the ends of the long bones The time of such development is specific for each center some appearing before birth and some as late as adolescence This epiphyseal (pronounced epi FISS ē al) ossification also progresses circumferentially, and finally all the original cartilage has been replaced except for a comparatively thin *epiphyseal cartilage epiphyseal plate* or *epiphyseal disk* which separates the shaft or diaphysis from the end or epiphysis The most recently formed bone at the end of the diaphysis is called the *metaphysis*

Growth of Long Bones Growth in diameter occurs most rapidly before maturity but can continue during nearly all of the life of the individual The periosteum produces concentric layers of bone on the outside, while a more or less proportional resorption of bones takes place in the medullary cavity enlarging its diameter

Growth in length is a continuation of ossification of the diaphysis toward the epiphysis However the epiphyseal cartilage continues to proliferate and keep the diaphysis and epiphysis separated At an age that is specific for each epiphysis varying from middle childhood to adulthood the epiphyseal cartilage ceases to proliferate and bony union (*closure*) takes place between diaphysis and epiphysis usually leaving an elevated ridge called the *epiphyseal line* on the surface of the matured bone

Trained physical educators often pay attention to the size of the bones as seen at the wrist, ankles and hips, in order to get a better estimate of an individual s capacity for bearing weights and stresses

Growth of Short Bones A short bone usually grows as if it were an epiphysis except that it maintains its independent identity

Influence of Trauma Numerous factors affecting bone growth were mentioned earlier in this chapter in the discussion of Wolff's Law In addition bone growth may be affected adversely by trauma Either a single catastrophic force or repeated severe insults can stop bone growth or dislocate the growing parts at the epiphyseal cartilage Interrupted growth is often considered to be more serious than a clean fracture in a fully ossified area of the same bone partly because pain and deformity are less obvious at the time of injury resulting in the delay of corrective measure until an irremediable defect has resulted Although cartilage is superior to bone in its ability to withstand certain kinds of stresses because of its greater flexibility and compressibility the epiphyseal cartilages are areas of great susceptibility to injury

Most of the major epiphyses do not close until seventeen to nineteen years of age Therefore many orthopedists regard football wrestling pyramid building and other stressful contact sports as undesirable during the period of bone immaturity From the anatomical point of view the following questions are pertinent

How serious is the danger of anatomical injury?
Is it greater in the organized sports programs than in the unsupervised sand lot activities which it replaces?
Can the rules be modified to minimize the danger of trauma?
Is adequate protective equipment available and used?
Is there adequate medical supervision of injuries?
Are medical examinations required of participants?
Are the managers teachers coaches, and officials aware of anatomical physiological factors in growth and development and do they use their prestige and authority in such a manner as to protect the safety of the participants?

Ossification Dates The statement that the age at which epiphyseal fusion takes place is specific for each epiphysis should not be interpreted too literally It is true that the fusion ages at various centers provide an amazingly accurate physiological time clock but the clock can run slow or fast according to state of endocrine secretion health, and nutrition of the individual Undoubtedly

TABLE 1 —Ossification Dates for Typical Long Bones

Center of Ossification	*Appearance Date*	*Epiphysis*	*Closure Date*
HUMERUS			
Body	8th fetal week	Head with tubercles	6th year
Head	1st year	Distal end with body	16th–17th year
Capitulum	2nd year	Head with body	20th year
Greater Tubercle	3rd year		
Lesser Tubercle	5th year		
Medial Epicondyle	5th year		
Trochlea	12th year		
Lateral Epicondyle	13th–14th year		
ULNA			
Body	8th fetal week	Olecranon with body	16th year
Head	4th year	Distal end with body	20th year
Olecranon	10th year		
RADIUS			
Body	8th fetal week	Proximal end with body	17th–18th year
Distal end	2nd year	Distal end with body	20th year
Proximal end	5th year		
FEMUR			
Body	7th fetal week	Lesser trochanter	
Distal end	9th fetal month	with body	Puberty
Head	1st year	Greater trochanter	
Greater Trochanter	4th year	with body	Puberty
Lesser Trochanter	13th–14th year	Head with body	Puberty
		Distal end with body	20th year
TIBIA			
Body	7th fetal week	Distal end with body	18th year
Proximal end	Birth	Proximal end with body	20th year
Distal end	2nd year		

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Growth of Long Bones Growth in diameter occurs most rapidly before maturity but can continue during nearly all of the life of the individual The periosteum produces concentric layers of bone on the outside while a more or less proportional resorption of bones takes place in the medullary cavity, enlarging its diameter

Growth in length is a continuation of ossification of the diaphysis toward the epiphysis However, the epiphyseal cartilage continues to proliferate and keep the diaphysis and epiphysis separated At an age that is specific for each epiphysis varying from middle childhood to adulthood, the epiphyseal cartilage ceases to proliferate and bony union (*closure*) takes place between diaphysis and epiphysis, usually leaving an elevated ridge called the *epiphyseal line* on the surface of the matured bone

Trained physical educators often pay attention to the size of the bones as seen at the wrist, ankles and hips in order to get a better estimate of an individual s capacity for bearing weights and stresses

Growth of Short Bones A short bone usually grows as if it were an epiphysis except that it maintains its independent identity

Influence of Trauma Numerous factors affecting bone growth were men tioned earlier in this chapter in the discussion of Wolff s Law In addition bone growth may be affected adversely by trauma Either a single catastrophic force or repeated severe insults can stop bone growth or dislocate the growing parts at the epiphyseal cartilage Interrupted growth is often considered to be more serious than a clean fracture in a fully ossified area of the same bone partly because pain and deformity are less obvious at the time of injury resulting in the delay of corrective measure until an irremediable defect has resulted Although cartilage is superior to bone in its ability to withstand certain kinds of stresses because of its greater flexibility and compressibility the epiphyseal cartilages are areas of great susceptibility to injury

Most of the major epiphyses do not close until seventeen to nineteen years of age Therefore many orthopedists regard football wrestling pyramid building and other stressful contact sports as undesirable during the period of bone immaturity From the anatomical point of view the following ques tions are pertinent

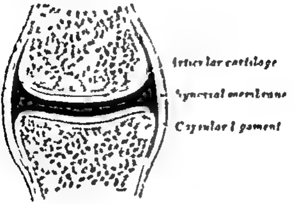

FIG 6

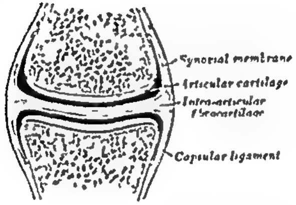

FIG 7

FIGS 6 and 7 —Typical diarthrodial joints with and without intra articular fibrocartilage (*Gray's Anatomy*)

partitions the joint cavity into two parts This makes it resemble a synchondrosis or cartilaginous articulation (Table 2) except that the latter has no cavity or synovial membrane The sterno-clavicular and distal radio ulnar joints are diarthrodial joints having fibrocartilage disks The attachments of these disks have peculiarities which enable them to assist in holding the bones together

The ligamentous capsules sometimes have definite thickenings on one or more aspects and these are sometimes named as separate ligaments In addition, there are typically several other ligaments which join the two bones and which are discrete from the capsule Ligaments are tough and practically non elastic Their function is to bind bones together to prevent dislocation, and to limit the kinds and ranges of movements if constantly applied, may result in their gradual lengthening—even to the point of destroying their function of maintaining the integrity of the joint

Tendons and sheets of fascia cross most joints Although their function is usually considered to be the transference of muscle tension so as to cause movement the fact that they hold bones together should never be overlooked Muscles must be responsible for bearing most of the gravitational and other stresses tending to dislocate the bones of a joint Because most muscles insert

there are racial geographical and hereditary differences although these have not as yet been adequately determined On the average a given epiphysis will ossify and growth in the length of the bone will cease from one to three years earlier in a female than in a male Trauma or overstrain may cause premature closure but ill health and malnutrition are likely to delay the date None of the epiphyses of the limbs fuse before puberty, but all of the epiphyses will normally be fused before age twenty one Average times of epiphyseal closure of typical long bones are given in Table 1

A youngster who is larger than average or who is obese is often subjected to unwarranted epiphyseal stresses His bulk may give a false impression of the degree of his bony maturity For this reason age should be a factor in athletic classification indices and sports leaders should not (for example) always put the biggest boy on the bottom of a pyramid in gymnastic lessons X ray pictures of the degree of ossification of carpal bones provide a precise *estimation of skeletal and physiological maturity of pre adolescents* but are seldom used because of the expense

THE ARCHITECTURE OF JOINTS

Types of Joints The junction of two bones is called a *joint* or *articulation* There are three classes of joints the *synarthrodial* or immovable the *amphiarthrodial* or slightly movable and the *diarthrodial* or freely movable The *first two classes have no true joint cavity the third class has a joint cavity and* is subdivided into seven types The classification and terminology of joints are presented differently by various authors A reasonably complete listing of types and terms is presented in Table 2 with descriptive explanations but students are cautioned to be alert for small differences in classification when consulting other source books Each specific joint of the body has its own peculiarities

Diarthrodial Joints The diarthrodial freely movable, or synovial joints are of greatest interest to students of human motion The typical structural aspects are shown in Figures 6 and 7 The weight bearing or articular sufaces of the bones are covered with a layer of hyaline cartilage known as *articular cartilage* Being resilient but not especially brittle this cartilage absorbs shocks prevents direct wear on the bones and modifies the shapes of the bones to insure a better fit It has no nerve or blood supply of its own In some joints the articular cartilages show specialized modifications and are given distinct names as is the case with *glenoid labrum* of the shoulder joint and the *semilunar cartilages* or *menisci* of the knee

A ligamentous sleeve called the *capsule* or *capsular ligament* is attached firmly to both bones of the joint enclosing it completely This capsule is lined internally by a thin vascular *synovial membrane* which secretes *synovial fluid* or *synovia* into the *joint cavity* The synovial fluid provides nourishment to the articular cartilages and serves to lubricate the joint Normally only a tiny bit of synovial fluid is present and there is a slight negative pressure (suction) in the joint cavity Thus the cavity is difficult to find and explore in dissection unless it has previously been injected so as to expand it Injury *or irritation however causes profuse secretion of synovial fluid sometimes* causing evident swelling

Some diarthrodial joints have an intra articular *fibrocartilage disk* which

at very small angles a large component of muscular force is usually directed along the bone toward the joint, tending to reinforce the joint by pulling the bones together. The ligaments constitute the second line of defense against dislocation, and their lesser extensibility enables them to bear stresses which have elongated the muscles and overcome the ability of the tendons to protect the joint. The ligaments thus provide emergency protection, but since ligaments will yield to continuous and regular stretching, it remains for the tendons and muscles to guard the joints most of the time.

Bursae and Tendon Sheaths. Wherever soft structures are frequently submitted to frictional rubbing on a bony protuberance, the friction is reduced by the appearance of tough connective tissue and some form of synovial sac. Even tendons cannot withstand constant friction on a bone without further protection. Therefore they are surrounded by a cylindrical sac consisting of two layers of synovial membrane enclosing a cavity into which synovial fluid is secreted—this is called a *tendon sheath*, and its function is lubrication. Non-tendinous soft structures are similarly protected. Thus, the fascia and skin at the back of the elbow are separated from the olecranon process by a simple synovial sac called a *bursa*. Bursae occur in many other places. For example, as the supraspinatus muscle passes under the acromion process, it is separated from that hard structure by the *sub-acromial bursa*; similarly the patellar ligament is protected from the head of the tibia by the *deep infrapatellar bursa*. Bursae and tendon sheaths are not parts of joints in a technical sense, but may be regarded as associated structures.

ACTIONS OF JOINTS

Kinesiologists require precise terminology to describe joint movements and muscle actions. For the purpose of defining joint movements, it is always assumed that the body is in *anatomical position*, that is, elongated as if suspended by its skull from a hook, with arms and legs dangling and palms of the hands facing forward. The skeleton in Figure 8 is in anatomical position except that its right hand has been turned in toward the thigh.

Flexion at any joint takes place when any body segment is moved in an antero-posterior plane so that its anterior or posterior surface approaches the anterior or posterior surface, respectively, of an adjacent body segment. Thus, moving the left limb from anatomical position to scratch the back of the left shoulder blade involves flexion of the arm at the shoulder joint, of the forearm at the elbow, of the hand at the wrist, and of the fingers at the metacarpo-phalangeal and inter-phalangeal joints. Bringing the front surface of the thigh toward the abdomen is hip flexion. Bringing the calf of the leg toward the back of the thigh is knee flexion. Raising the foot toward the tibia is ankle flexion. Curling the toes is toe flexion. *Extension* is the reverse—the moving from a flexed position back toward the anatomical position.

Abduction means moving a segment away from the center line of the body. Once started, the movement is called abduction throughout its entire range even though, as in the case of abducting the arm at the shoulder joint, the part seems to be coming back toward the center line of the body during the second 90 degrees of its excursion. *Adduction* is the reverse of abduction—the moving from a position of abduction back toward the anatomical position. There is no abduction or adduction at the elbow or knee joints. At the wrist,

TABLE 2 —Classification of Joints by Structure and Action

KIND	*CLASS*	*TYPE* *Common Name*	*TYPE* *Technical Name*	*EXPLANATION AND EXAMPLES*
Without a joint cavity	I Synarthrosis (immovable)	A Fibrous	Suture*	Two bones grow together with only a thin layer of fibrous periosteum between *Eg* sutures of the skull
	II Amphiarthrosis (slightly movable)	B Ligamentous	Syndesmosis*	Slight movement permitted by meager elasticity of a ligament joining two bones which may be distinctly separated *Eg* coraco acromial joint mid radio ulnar joint mid tibio fibular joint inferior tibio fibular joint
		C Cartilaginous	Synchondrosis or symphysis	Bones are coated with hyaline cartilage separated by a fibrocartilage disk and joined by ligaments Motion is allowed only by deformation of the disk *Eg* between bodies of vertebrae symphysis pubis between manubrium and body of sternum
Having a joint cavity	III Diarthrosis (freely movable)	D Synovial 1 Gliding joint	Arthrosis or plane joint	Non axial Allows gliding or twisting *Eg* intercarpal and intertarsal joints
		2 Hinge joint	Ginglymus	Uni axial A concave surface glides around a convex surface allowing flexion and extension *Eg* elbow joint
		3 Pivot joint	Trochoid joint	Uni axial A rotation around a vertical or long axis is allowed *Eg* atlanto axial joint proximal radio ulnar joint
		4 Ellipsoid joint	Ellipsoid joint	Bi axial An oval ball and socket joint allowing flexion extension abduction adduction and circumduction but not rotation *Eg* carpo metacarpal (wrist) joint
		5 Condyloid joint	Condyloid joint	Bi axial A spheroidal ball and socket joint with no muscles suitably located to perform rotation which otherwise could take place *Eg* interphalangeal joints 2nd to 5th metacarpo phalangeal joints (but not of the thumb)
		6 Ball and socket joint	Spheroid or enarthrosis	Tri axial Spheroidal ball and socket allows flexion extension abduction adduction circumduction and rotation on the long axis *Eg* shoulder and hip joints
		7 Saddle joint	Saddle joint	Tri axial Both bones have a saddle shaped surface fitted into each other Allows flexion extension abduction adduction circumduction and slight rotation *Eg* carpo metacarpal joint of the thumb

*Some classification systems include both sutures and syndesmoses under the heading of fibrous joints Both sutures and syndesmoses tend to ossify completely in later life in which case the union is known as a *synostosis*

abduction is also called *radial flexion*, and adduction is also called *ulnar flexion*

Rotation around the long axis of a bone can take place for example at the shoulder, hip, and knee joints *Inward rotation* occurs when the anterior surface turns inward, *outward rotation* is the reverse of this when the anterior surface turns outward With regard to rotation the anatomical position is often regarded as the *neutral position* thus from a position of inward rotation the thigh may be rotated outward to the neutral position and then further rotated outward

Circumduction is a movement in which a body part describes a cone, with the apex at the joint and the base at the distal end of the part There is no term to distinguish circumduction around a base of small radius from that around a base of large radius Circumduction does not involve rotation, therefore it may occur in biaxial joints like the metacarpo-phalangeal joints by a combination of flexion abduction extension, and adduction

Hyperextension means a continuation of extension past anatomical position, usually Thus from the normally-extended anatomical position of the elbow, slight further extension is possible in some people This is characteristically seen in gymnasts In no case does the prefix hyper indicate a different motion but only an exceptional continuation of the movement involved

Certain movements of some articulations require special consideration Descriptions and terminology for such movements of the radio ulnar joint first carpo metacarpal joint and thumb, foot and ankle and the spine or trunk are given in detail in Chapters 11, 12, 15, and 16 of this text

In the tremendously varied activities of athletics, aquatics combatives, gymnastics dance, and recreational and vocational pursuits the joint actions can become complex indeed Confusion in terminology must be carefully minimized For this reason, it is perhaps better to describe a joint action as (for example) hip flexion or shoulder joint abduction rather than thigh flexion or arm abduction, although both usages are correct If the term thigh flexion is employed beginning students are sometimes confused when it is used to refer to a motion of the pelvis forward onto the thigh as in doing situps The word thigh seems to indicate to some that the thigh must be the moving part whereas there is no such connotation if hip flexion is used because attention is centered upon the joint rather than on the body part The preference is strictly pedagogical

MOBILITY OF JOINTS

The range of motion for any particular joint action may be limited by ligaments shortness of muscles and fascia occlusion of soft tissues and impingement of bone against bone The latter is a factor only in a few instances, such as elbow extension Flexibility is a factor in physical fitness [4, 5] sports ability posture correction and rehabilitation

In clinical practice the amount of recovery of an injured joint is sometimes estimated by measuring its range of movement with a goniometer and comparing the findings with the values found in tables provided for this purpose The conclusions reached may be misleading for any of several reasons Exact technique in the use of the goniometer is essential and unless the operator is both skilled and experienced the values obtained may miss the truth even

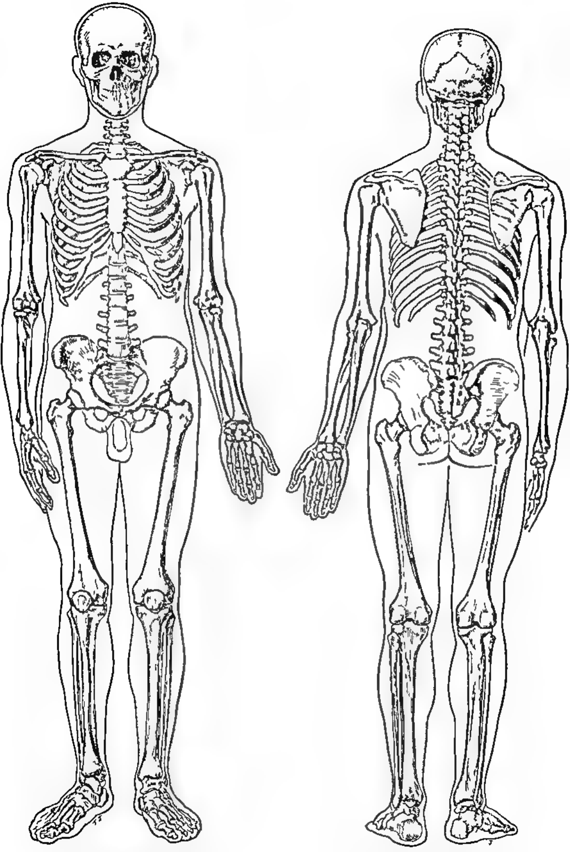

FIG 8 —The skeleton as projected on the surface of the body viewed from in front and from behind (Eycleshymer and Jones *Hand Atlas of Clinical Anatomy*)

weight lifting and gymnastics present flexibility patterns which are typical of each sport and that there are significant differences between these athletes and sixteen year old boys in general In addition to these factors women tend to be more flexible than men and flexibility varies with body build obesity, and occupational habits Heavy work through restricted ranges of motion may lead to muscle boundness" as seen in pick and shovel laborers but a rounded program of progressive resistance exercise is likely to increase flexibility beyond normal ranges [8, 9]

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though a reliable instrument is used The effect of gravity, the relative positions of contiguous parts or the fact that the axis of motion may shift as movement proceeds, if overlooked may all be sources of possible error Then, too, two different types of goniometers will not necessarily give the same values even when measuring the same movement on the same joint by the same investigator Even tables provided may be in error Values for the normal range of joint motion obtained and published by various investigators exhibit a remarkable lack of agreement The disparity can often be traced to the factors mentioned above Until satisfactory tables of norms are available for both sexes and for reasonable age increments, their use should be approached with caution In most cases it is usually possible and far more satisfactory to establish the normal range of joint movement and to estimate the degree of recovery from injury by comparing the amount of movement possible in the injured joint with that of the corresponding intact articulation Physiotherapists must measure range of motion to determine residual effects of paralysis and trauma, and must understand ranges which can be tolerated under manipulative therapy

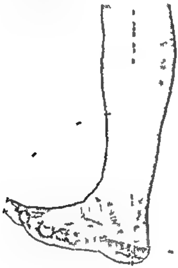

FIG 9—Voluntary dorsal flexion Normal dorsiflexion ranges between 10 and 20 degrees Plantar flexion is about 35 degrees (Lewin *The Foot and Ankle*)

FIG 10—Voluntary plantar flexion (Lewin *The Foot and Ankle*)

The establishment of normal tables for range of motion of joints is hampered by the variety of factors giving rise to individual differences Usage is perhaps the greatest variable as startlingly shown by observing the number and extent of motions possible in the foot joints of an infant in comparison to those possible in an adult who has for years restricted motion by wearing modern shoes Children from ages ten to sixteen show a generalized pattern of decreasing flexibility [6] Leighton[7, 8] has shown that swimmers, baseball players basketball players, field event performers and champions in wrestling

however, the flow is impeded and the blood pressure rises Smooth muscle is innervated by both the sympathetic and parasympathetic nervous systems Its action is usually involuntary and it can function in the absence of its extrinsic nerves

Cardiac Muscle Cardiac muscle is striated but is a *syncytium* that is the cells are connected instead of being separate Once an impulse starts in any part of this syncytium it involves the entire network of muscle fibers The sarcoplasm is more abundant than in striated muscle the nuclei are in the center of the cells and the striations are less distinct This muscle is not under voluntary control The sympathetic nervous system increases the rate and the force of cardiac muscle contraction the parasympathetic diminishes both of them Cardiac muscle possesses four basic properties (1) rhythmicity, or the property of generating periodic impulses (2) conductivity or the property of transmitting these impulses through the muscle (3) irritability or the property of responding to stimuli and (4) contractility, or the property of contracting in response to a stimulus Like smooth muscle it probably contains pain endings but no proprioceptors

Striated Muscle Striated muscles are composed of thread like fibers displaying alternating dark and light bands Each fiber is actually a greatly elongated, multinucleated cell It may be over 30 cm in length and have a diameter of 0 01 to 0 1 mm Each cell is separate According to one estimate there are about 250 million striated muscle fibers in the body [1] They are innervated by the cranial or the spinal nerves and are under voluntary control This type of muscle contains both pain endings and proprioceptors Its principal functions are body movement and the maintenance of posture This is the type of muscle with which kinesiologists are primarily concerned and the following discussion of muscle structure and function will deal only with striated muscle

STRUCTURE OF STRIATED MUSCLE

Organization of Muscle Fibers The elongated polynucleated cell comprising a muscle fiber is enclosed in the *sarcolemma* a thin structureless, selectively permeable membrane adhering to an outer network of reticular fibers termed *endomysium* This keeps the adjacent fibers from merging into a single jelly-like mass and isolates them so that they can act as separate units The inside portion of the cell is composed of a specialized but undifferentiated protoplasm termed *sacroplasm* This is a protein *sol* (a liquid solution of colloids) of relatively low viscosity Embedded within the sarcoplasm are the *myofibrils* semi crystalline protein *gels* (firm solutions of colloids) which are responsible for the contractile activity These run parallel to the axis of the fiber, merging into the sarcolemma at each end of the cell They are extremely small, having a diameter ranging from 0 5 to 2 0 microns Lipoprotein granules termed sarcosomes Adenosinetriphosphatases, fat granules glycogen granules, and reticulated structures known as microsomes are also found in the sarcoplasm

Myofibrils draw the *substrates* (materials upon which the enzymes act) necessary for contraction from the sarcoplasm and diffuse back into it the products of the enzymes associated with contraction [2] Seen under polarized light the myofibrils consist of alternating dark (anisotropic) and light (isotropic) bands, as seen in Figure 11 Under plain light this coloring is reversed

Chapter 3

The Structure and Action of Striated Muscle

THE muscles of the body are composed of three different types of contractile tissue In certain characteristics all are quite similar They are affected by the same kind of stimuli they produce an action potential soon after stimulation, they possess the ability to contract the force of the contraction (within physiological limits) is dependent upon their initial length they have the ability to maintain muscle tone they will atrophy from inadequate circulation and will hypertrophy in response to increased work In certain other respects they may show marked differences

Smooth Muscle Smooth or involuntary muscle forms the walls of the hollow viscera such as the stomach and bladder and of various systems of tubes such as are found in the circulatory system the alimentary tract the respiratory system, and the reproductive organs These muscle cells possess myofibrils but they do not have cross striations and have only one nucleus Probably smooth muscle contains pain endings but no proprioceptors Compared with skeletal muscle they display more sluggish contraction greater extensibility the power of more sustained contraction and of rhythmic contraction greater sensitivity to thermal and chemical stimuli and a longer chronaxie The minimum amount of electrical current required to produce a response in a muscle is termed the *threshold stimulus* The *time* required for a current of twice this strength to produce a response is called the *chronaxie* The chronaxie of the muscles varies those of nerves innervating pale muscles are shorter than those of nerves innervating red muscles the chronaxies of smooth muscle are longer than those of skeletal muscle The general rule seems to be that a short chronaxie is related to quick contraction a long chronaxie to slow contraction Charts have been prepared in which the muscles are classified into groups according to their chronaxies Since changes in chronaxie are correlated with changes in physiologic function these have considerable value in determining degenerative and regenerative changes in nerves and muscles Contraction of smooth muscle forming a hollow organ will cause that organ to empty In the case of the digestive tract waves of contraction propel its contents onward If contraction occurs in the circulatory system

transmission of impulses from the sarcolemma to the myofibrils The area lying between any two Z lines is termed a *sarcomere* and is believed to form a compartment having common nerve and blood supplies and in which identical chemical processes occur[3] It has been suggested that the Z lines activate the fibrils when stimulated by a reduction in membrane potential[4]

The M band is so-called to indicate its position in the middle of the sarcomere Its function and that of the N (Nebenscheide) disks is not understood On either side of the M band is a strip of less dense material—the H zones It has been postulated that A I and H bands are made up of two sets of filaments, which slide past each other when the muscle shortens or lengthens In this theory the thicker filaments are assumed to be largely composed of

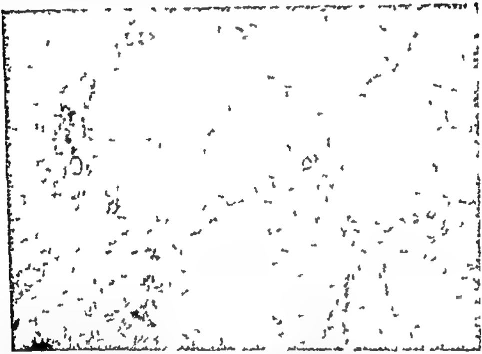

FIG 13 —Cross sectional view of muscle fibrils showing primary and secondary muscle filaments as seen under the electron microscope It has been suggested that when changes in the length of muscle occur, the two sets of filaments slide past each other (× 90 000) (Huxley)

myosin, the thinner ones of actin Actomyosin makes up about 80 per cent of the structural proteins extractable from muscle in the ratio of 60 per cent myosin to 20 per cent actin The myosin filaments are found only in the A band the actin filaments extend through the I bands into the A bands, but do not enter the H zone This accounts for the lesser density of this area[4, 5]

There is a great deal of evidence that muscle consists of a contractile component in series with a passive elastic element through which the contractile element must exert its force In part the elastic element may be a property of the Z zones[6]

Since the investigations of Morpurgo it has been believed that increases in hypertrophy resulted from increases in the cross section of the muscle fibers and not from an increase in the number of muscle fibers[7] Very recent studies[8]

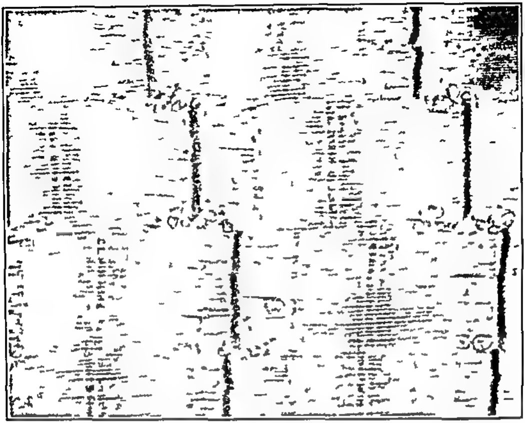

Fig 11 —Section through striated muscle from a rabbit as seen under the electron microscope at a magnification of 24 000 × The dense A bands bisected by H zones and the light I bands bisected by Z lines are clearly visible (Huxley)

There is some disagreement among students concerning the various bands and lines In part this may be because certain of them exist only at a given stage in the contraction cycle The diagram shown in Figure 12 represents only well substantiated divisions of normal resting myofibrils

The Z line is believed to be a comparatively dense material which adheres to the sarcolemma stabilizes the structure, localizes damage, and aids in the

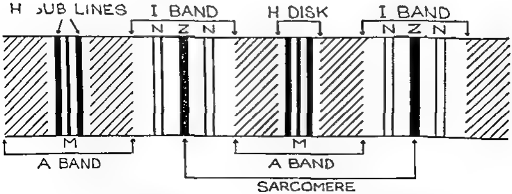

Fig 12 —Schematic representation of the myofibril from skeletal muscle (After Perry)

are extremely thin and provide for an easy transfer of needed substances from the blood to the fiber itself There is an intermittent ebb and flow of blood through the capillary network, due to the opening and closing of capillaries and arterioles in response to local tissue changes If the fiber is inactive its metabolic needs are slight and little or no blood flows through its capillaries Upon commencing exercise the acid metabolites resulting from muscular contraction cause the capillaries to dilate, thus permitting an influx of needed blood

Faster vasomotor changes are probably due to the sympathetic vasoconstriction and vasodilation These independent unsynchronized contractility changes are believed responsible for the basal vasomotor tone and are probably more important in the vasodilatation accompanying muscular exercise than are the local metabolites The principal regulation of the blood vessels for homeostatic purposes is probably through the sympathetic innervation,[10] although humoral factors also play a role The working of the nervous system is clearly seen in the physiological changes which accompany the anticipation of exercise

There is considerable experimental evidence indicating that the body responds to meet the need for a greater blood supply in the heavily exercised muscle by the development of additional new capillaries within the muscle One experimental study reported this increase was about 45 per cent [11]

During a strong sustained muscular contraction the circulation is temporarily arrested Within a short time however, the limb volume begins to rise, indicating that while strong muscular contraction does compress the vessels this compression is insufficient to prevent them from dilating to a certain extent under the influence of dilator substances released from the muscle fibers [12] Static contractions, such as standing at attention, weight training and gymnastics may thus hinder the venous return to the heart especially when the Valsalva maneuver is involved [13] During dynamic exercise the rhythmic contractions of the skeletal muscle exert a strong pumping action on the blood flow During the periods of relaxation the veins of the muscle become filled with blood During contraction the blood is squeezed out of the muscle The presence of valves in the veins permits it to move only toward the heart Immediate relaxation after strenuous exercise results in a removal of this pumping action and the venous return to the heart may become insufficient to maintain the cardiac output If an athlete after an exhausting race, relaxes and is carried in a vertical position by his teammates the sudden stoppage of this pumping action may reduce the venous return

Innervation of Muscle Not only are the muscles penetrated and served by the vessels of the circulatory system but they are also well supplied with nerves One or more nerves containing both motor and sensory fibers enter each muscle from the central nervous system Such nerves contain a large number of motor axons each of which is thought to serve a single fasciculus At the fasciculus the nerve divides into a number of twigs (*Fig 14*) each of which has its end plate embedded in a single muscle fiber, providing it with direct communication with the central nervous system The number of muscle fibers innervated by a single motor nerve fiber varies from one to several hundred Under normal conditions the group of muscle fibers innervated by a single nerve fiber contracts as a single *muscle unit*

suggest that exercise may produce an increase in the number of myofibrils within the fibers and that disuse atrophy is associated with a loss of myo fibrils but confirmation of this claim will have to await further experimental evidence

Organization of Whole Muscles Units of 100 to 150 muscle fibers are bound together with a connective tissue called *perimysium* to form a bundle termed a *fasciculus* Several fasciculi are in turn bound together by a sheath of perimysium to form a larger unit These units are enclosed in a covering of *epimysium* to form a muscle The various sheaths merge to form the tendon, which attaches the muscle to the bony surface of origin or insertion The thickness and strength of the external sheath will vary greatly depending upon the location of the muscle It is usually very heavy if the muscle is situated near the distal end of a limb where the muscle might be exposed to blows and abrasions Usually there is additional fascia covering the muscle to give further protection On the other hand a muscle situated deep within the body and consequently well protected such as the psoas, has a minimum of connective tissue in the various sheaths

These sheaths form a sort of structural framework for the muscle This structure is tough and somewhat elastic and will return to its original length even after having been stretched as much as 40 per cent The fact that the relative amounts of connective and contractile tissue vary greatly from muscle to muscle has at times been disregarded and has led to great discrepancies when experimental physiologists have reported the physical properties of muscle

Red and Pale Fibers In some fibers the sacroplasm contains relatively large amounts of *myohemoglobin* and much granular material which gives them a much darker and redder appearance than other fibers which have less sarcoplasm few granules, very little myohemoglobin These two types of muscle fibers are known as red and pale muscle respectively In red fibers the pigment may serve as a means of storage of oxygen Hence these muscles are better adapted to long sustained contraction such as is required in maintaining posture, which has a tendency to produce ischemia (temporary deficiency of blood) Pale fibers are better adapted to perform fast contractions In the domestic fowl the legs which are in continuous use are largely composed of red fibers whereas the wings and breast which are of little use are largely composed of pale fibers In contrast wild fowl which engage in long flights have red fibers in the wings and breast as well In man the common type of muscle is a mixed one containing varying amounts of red and pale fibers, depending on its task Leg muscles such as the soleus and extensors which are engaged in the arduous task of posture maintenance have high proportions of red fibers while the flexors which do not have to be used continually have relatively higher proportions of pale fibers Experimental findings led Bach[9] to conclude that if a red muscle is transplanted to do the work of a pale muscle it develops characteristics typical of a pale muscle

Nutrition and Blood Supply Each muscle receives its supply of oxygen sugar and other foodstuffs from the circulatory system and is therefore necessarily supplied with one or several arteries Each artery divides into smaller arterioles and they in turn finally divide into an incredible number of small capillaries which lie in the endomysium The walls of the capillaries

TABLE 4 Motor Units and Muscular Tension in the Cat

Muscle	*No. of Motor Units*	*Average Tension (in Grams)*
Soleus	250	9 5
Extensor longus digitorum	330	8 1
Gastrocnemius—median head	430	23 1
Semitendinosus	630	5 02

which control movements of the eye where great precision is required Motor units with as few as three fibers have been identified

Tonus. The feeling of firmness in a normal muscle is ascribed to muscular tone Muscular tone has traditionally been explained as being a state of partial tetanus due to low frequency discharges from the ventral horn cells If the motor nerve is lesioned the tone disappears and the muscle lengthens and becomes flabby The level of activity has been considered as being lower but not essentially different from that involved in normal voluntary movement More recently this theory has been subjected to strong criticism on the grounds that a resting muscle is electrically silent and it has been suggested that muscular tone is a function of the natural fullness (turgor) of the muscular and fibrous tissue and of the response of the nervous system to stimuli [17, 18]

Muscles that are much used are apt to have more tone than those used less When the tone in two antagonists is different the segments upon which they act may deviate from their normal position This is the cause of one type of postural defect

The fact that muscle groups can be made to develop increased tonus and certain muscles can be shortened by exercise within a limited range of movement is used in some phases of corrective physical education Through such procedure certain muscles of the dorsal aspect of the shoulder girdle may be shortened and their tonus increased adducting the scapula, with resultant stretching and temporary change of tone of certain antagonistic muscles of the ventral aspect This will result in a shifting of the relative position of the shoulders, causing them to be pulled back more than heretofore Still another factor to be considered in this connection is that when a muscle is habitually held in a shortened position and is used in time the muscle will shorten and accommodate itself to the new length with the restoration of normal tonus the joint affected will then have a new resting position This implies, of course that the antagonistic muscle group will be correspondingly stretched, and that it will also accommodate itself to the new length and re establish its normal tone This readjustment is a common experience of children who wear shoes in winter, go barefoot in the summer months and then revert to the wearing of shoes upon the advent of cold weather When footwear is discarded the soleus and gastrocnemius are stretched and the antagonistic muscles shorten When shoes are again worn the reverse process occurs

Numbers and Types of Muscles The muscles make up approximately 40 to 45 per cent of adult body weight It has been estimated that there are about 250 million individual striated muscle fibers in the body The voluntary muscular system includes approximately 434 muscles, but only about 75 pairs are

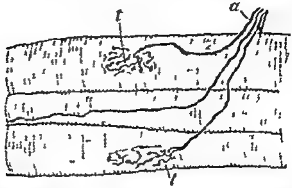

FIG 14 —Muscle magnified showing muscle and nerve fibers (*Gray s Anatomy*)

A nerve cell its axon with its various branches, and the muscle fibers served are known as a *motor unit* The motor unit may be considered the fundamental functional unit of neuro muscular contraction The sarcolemma serves as a container for the muscle fiber and aids in preventing the stimulating effect of a nerve impulse from spreading from one muscle fiber to its neighbors, although there is evidence that when there is a massive stimulation of one muscle it may irradiate a nearby muscle [14] Estimates have been made of the number of muscle fibers and motor units in human muscles [15] Some typical examples are given in Table 3

TABLE 3 —Estimated Number of Muscle Fibers and Motor Units in Human Muscles

Muscle	*Mean Dia of Mus Fibers (Microns)*	*No of Muscle Fibers*	*No of Large Nerve Fibers*	*Calculated No of Motor Units*	*No of Fibers per Motor Unit*
Platysma	19 8 ± 0 3	27 100	1 826	1 096	25
Brachio radialis	34 0 ± 0 8	129 200	525	315	410
Tibialis anterior	56 7 ± 0 2	250 000	742	445	657
Gastrocnemius medial head	54 1 ± 1 2	1,120 000	965	579	1 934

Not only does the number of motor units in different muscles vary greatly but the average tension in tetanic contraction developed by the motor units of one muscle may differ greatly from that of another A study has been made of the number of motor units and the tension which may be exerted by the muscles of the cat [15] Some typical examples are shown in Table 4

In the case of the thumb where not only strength but the ability to do delicate and accurate work is required each motor unit is composed of relatively few muscle fibers Because of this structure forces exerted by the thumb can be changed by relatively small increments as compared with the heavy postural muscles The smallest motor units are to be found in the muscles

TABLE 4.—Motor Units and Muscular Tension in the Cat

Muscle	*No. of Motor Units*	*Average Tension (in Grams)*
Soleus	250	9.5
Extensor longus digitorum	330	8.1
Gastrocnemius—median head	430	23.1
Semitendinosus	630	5.02

which control movements of the eye, where great precision is required. Motor units with as few as three fibers have been identified.

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Numbers and Types of Muscles. The muscles make up approximately 40 to 45 per cent of adult body weight. It has been estimated that there are about 250 million individual striated muscle fibers in the body. The voluntary muscular system includes approximately 434 muscles, but only about 75 pairs are

involved in the general posture and movement of the body and will be considered in this text The others are smaller and are concerned with such minute mechanisms as those controlling the voice, facial expression and the act of swallowing Some muscles are in flat sheets like the trapezius and the transversalis, some are long and slender like the sartorius and the peroneus longus some are spindle shaped like the biceps and the pronator teres, some are fan shaped, like the pectoralis major Most of them are of such irregular shape that a classification based on form is not practicable Each is named some of the names indicating their form, as in the case of the rhomboid and teres major some indicating their action as the levator and the supinator some indicating their location, as the intercostal and supraspinatus some indicating the bones which they join, as the brachioradialis and the sternomastoid

Longitudinal and Penniform Muscles The musculoskeletal machine is basically an arrangement providing relatively large forces for the rapid manipulation of long lever arms This mechanical system possesses only low mechanical advantages with the result that the high speeds of motion are made possible only at the price of great exertion While the human body may be said to be specialized more for speed than for strength the forces required for various movements are relatively enormous It may, for example require 300 pounds of tension in the deltoid to enable it to raise an arm and hand holding a 10 pound weight to 80 degrees of elevation

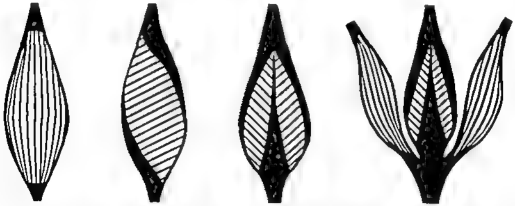

FIG 15 —Diagrams showing kinds of arrangements of fibers of skeletal muscles A Fusiform B Unipennate C Bipennate D Multipennate (Douglas)

The internal structure of muscles that is the arrangement of their fibers bears an important relation to the force and distance of their contraction There are two main types of muscle structure the longitudinal or *fusiform* and the *penniform* but there are many variations from each basic type The longitudinal is the simpler of the two forms, it consists of parallel fibers running the length of the muscle In general muscle which is long and slender is weak but can shorten through a relatively large distance while muscle which is short and broad has much strength of contraction but can exert it through a proportionately short distance The sartorius for example, is a narrow band of extremely long fibers well suited to contract with little force through a relatively great distance, whereas the intercostals consisting of a great number

of very short fibers are constructed to contract with considerable force through a very short distance

Fully three fourths of all the muscles in the human body are so situated that they need to exert more strength than a longitudinal muscle would afford, while the latter s greater extent of contraction would be wasted As a consequence the longitudinal muscles are replaced by the penniform Penniform muscles are shaped like a feather, with the tendon in place of the shaft and the muscle fibers in place of the barbs Since the muscle fibers are arranged diagonally to the direction of pull, more fibers can be brought into play, but the range of motion is reduced

Penniform muscles come in several different arrangements

Unipennate—Muscle to one side of the tendon, as in the semimembranosus

Bipennate—Muscle converges to both sides of a tendon, as in the rectus femoris

Multipennate—Muscle converges to several tendons, giving a herringbone effect as in the deltoid

Some of these arrangements are depicted in Figure 15

Origin and Insertion When a muscle contracts strongly it tends to move both of the bones to which it is attached, but to simplify the problem it is usually assumed that the bone moving least is stationary The point where the muscle joins the stationary bone is called the *origin* of the muscle, and its point of attachment to the moving bone is called its insertion By this definition the insertion is the place where the force is applied to the moving lever and the distance from the insertion to the joint which serves as the axis of movement is the force arm of the lever It frequently happens that the bone that acts as the lever in one movement is stationary in another for example, when one lies on his back and then lifts his feet the trunk is stationary and the lower limbs are levers but when from the same starting position he rises to a sitting posture the limbs are stationary and the trunk is the lever The same muscles are involved in both cases, and it is evident that the origins and insertions are reversed when the movement is changed The question as to which end of a muscle is origin and which is insertion depends therefore on the movement made Although the matter is of importance for kinesiologists for the sake of clearness of description the custom of the anatomists will be followed and the end nearer the center of the body will be referred to as the origin The true origin and insertion can be told with ease when any mechanical problem is involved

ROLES IN WHICH MUSCLES MAY ACT

A muscle can do only two things develop tension within itself or relax The size shape and number of fibers of a muscle the type of joint traversed the nature of the tendinous or fleshy origin and insertion the angle and place of insertion, the mechanical advantage of the bone muscle levers and other factors may affect its actions In addition muscles may function singly or as members of a team in various combinations and patterns of movement The various roles which a muscle may play are designated by technical terms, some of which will be defined in the following section Unfortunately, these terms have been given varying connotations in different fields, and in some cases the usage has changed with the passage of time Any teacher or author

is forced to employ these definitions with a certain amount of arbitrariness and students who consult a variety of textbooks must determine carefully which definitions are accepted by particular authors

1 The Role of MOVER or AGONIST

If a muscle contracts concentrically, it is said to be a *mover* or *agonist* for the joint actions which result For example the movers for elbow extension are the triceps brachii and the anconeus Some muscles are movers for more than one action in a given joint, many may have single or multiple actions on each of two or more joints which they happen to traverse The biceps brachii for instance, is a mover for both elbow flexion and radio ulnar supination and in addition it is a mover for several shoulder joint actions, because of its two headed origin on the scapula It is an axiom that a muscle, when it contracts tends to perform all of the actions for which it is a mover, although some or all of these actions may be prevented from occurring in specific situations by contraction of other muscles or by some external force such as gravity

2 The Role of PRIME MOVER and of ASSISTANT MOVER

Movers are often subclassified as *prime movers* or as *assistant* or *secondary movers* for a given joint action A *prime mover* is a muscle primarily responsible for causing a specified joint action An *assistant mover* is a muscle which aids the prime mover to effect joint action In borderline cases, writers often disagree in distinguishing between prime and assistant movers In this text an attempt has been made to conform to the most general usage but it has sometimes been necessary to be arbitrary

The term *emergency muscle* may be used to designate an assistant mover which is called into action only when an exceptional amount of total force is needed The long head of the biceps brachii for example, is not often called into action when performing shoulder joint abduction but it may assist that action in times of great need and some therapists claim to have taught patients to abduct the shoulder joint by contraction of the long head after polio has paralyzed the deltoid and supraspinatus [19]

Some writers have stated that every muscle must have at least one prime mover function This rule appeals to one s sense of orderliness, but does not appear to have a clear biological basis The subclavius for example does not appear to be able to do any joint action very well and it is usually listed only as an assistant mover for shoulder girdle depression (See discussion of subclavius in Chapter 9, p 137)

Most two joint and multijoint muscles are listed as prime movers for action at their most distal joints but this is not a hard and fast law The actions of the biceps brachii the flexor digitorum profundus and the gastrocnemius for instance conform to this rule but the actions of the hamstring muscles do not

3 The Role of ANTAGONIST

An antagonist is a muscle whose contraction tends to produce a joint action exactly opposite to some given joint action of another specified muscle An extensor muscle is antagonistic, potentially to a flexor muscle Thus the

biceps brachii is an antagonist of the triceps brachii with respect to elbow extension, and to the pronator teres with respect to radio ulnar pronation The biceps is not an antagonist of the brachialis, because it cannot oppose any motion for which the brachialis is a mover

4 The Role of FIXATOR or STABILIZER

A *fixator* or *stabilizer* is a muscle which anchors, steadies or supports a bone or body part in order that another active muscle may have a firm base upon which to pull If a person reaches forward to pull open a resistant door, he must stabilize his body parts if he is to overcome the resistance To open the door, elbow flexion may be needed and if the scapula (for example) is not stabilized, the contraction of the biceps may cause a pulling forward of the shoulder girdle rather than an opening of the door When a muscle contracts, it tends to pull both of its ends toward its center, with equal force Typically, a person is desirous of causing motion only at one end of the muscle Therefore he attempts to stabilize the bone to which the opposite end of the muscle is attached

In the ideal case, a fixator or stabilizer muscle will be in static contraction In practice these terms are extended to include instances in which there is a slight motion in the "stabilized" part, so as to continuously adjust the stabilization to the requirements of the desired motion—this condition may be called a "moving fixation" or a "guiding action"

A good example of fixation or stabilization occurs in the floor pushup exercise The abdominal muscles contract statically during pushups, so as to prevent an undesirable sagging of the body in the hip and trunk region In this example the fixation is necessary not so much to provide a firm base for the action of other muscles as to counteract the action of gravity upon the hip and spine joints Turning to another example, the static contraction of the neck extensors may be cited as a fixation of the cervical spine in order to provide a firm base for the action of the sternocleidomastoid muscles on the anterior surface of the neck so that the latter can assist in lifting the rib cage during forced breathing after running a race Without such fixation the head may curl forward on the chest interfering with deep breathing

5 The Role of SYNERGIST

The term *synergist* has been used with so many different connotations, both historically and in contemporary works, that its meaning has become very generalized if not actually ambiguous Some writers define *synergist* as a muscle which acts along with some other muscle or muscles as a part of a team others use the term in a more restricted sense but there is little agreement among these viewpoints [20]

Wright[21] identified two specific kinds of synergy *helping synergy* and *true synergy* In this usage synergy in general is defined as a counteracting of undesired side action or secondary action on the part of active muscles *Helping synergy* occurs during the action of two muscles both of which have a common joint action and each of which have a second action which is antagonistic to that of the other As both of these muscles contract simultaneously they act together to produce the desired common action, and they act as helping synergists to each other as they counteract or neutralize each

other s undesired secondary action An example occurs in the sit up exercise from supine lying position Several abdominal muscles cooperate in producing spine flexion in this exercise, but we may for the moment consider only the right and left external oblique abdominal muscles Both of these muscles cooperate in flexing the spine since each is a prime mover for this action But the right external oblique is also a prime mover for right lateral spine flexion and for left spine rotation while the left external oblique is a prime mover for left lateral spine flexion and for right spine rotation The lateral flexion and the rotation tendencies, in opposite directions, are mutually counteracted, ruled out, or neutralized and the resultant motion is pure spine flexion

True synergy occurs when one muscle contracts statically to prevent any action in one of the joints traversed by a contracting two joint or multi joint muscle According to the axiom that a muscle tends to perform all of its possible actions when it contracts a two joint muscle will tend to cause movement at every joint which it crosses Sometimes however a two joint muscle must contract for the purpose of performing its actions at only one of the joints and in this instance another muscle must contract in order to prevent an undesired action from occurring at the other joint For example, when the fist is clenched, the extensors of the wrist act as true synergists If the wrist were not held extended, then the long flexors of the fingers would produce wrist flexion as well as finger flexion Now, flexion of the wrist added to flexion of the fingers stretches the tendons of the long finger extensors until they can yield no more at which point continued wrist flexion causes the fingers to open out and the grip to slacken This is the explanation of the success of the trick of compelling an opponent to drop a weapon from his hand by forcibly flexing his wrist

6 The Role of NEUTRALIZER

A *neutralizer* is a muscle which contracts in order to counteract rule out, or neutralize an undesired action of another contracting muscle Thus the term neutralizer ' is a synonym for describing the role played by a helping synergist or a true synergist as defined in the preceding section As a technical term it has the distinct advantage of avoiding the several different meanings which have been attached to the general term synergist by various authors and teachers

TEAM WORK AMONG MUSCLES

A muscle seldom if ever acts alone The simplest movement is based upon some static or dynamic posture implying a multitude of stabilizations in addition to the function of the agonists Since most muscles have more than one joint action as they contract they will ordinarily require the contraction of other muscles as neutralizers Movements against heavy resistance will ordinarily require the combined contraction of several muscles which are capable of producing a given joint action

The study of the actions of single muscles is an artificiality which is necessary for academic purposes As learners we cannot easily comprehend complex muscular interactions at first and we must resort to a piecework or part method of study Further our interest in movement is often analytic requiring understanding of the elements of movement even when these elements cannot be performed separately In therapy adapted physical education and

corrective work, we often need to know the limitations which are imposed by paralysis or trauma to individual muscles, or we may need to predict the functions which remain available by contraction of the non paralyzed or uninjured muscles These and other reasons justify the study of individual muscles and their actions

Our emphasis on single muscles and upon the components of movement should never be allowed to obscure the beautiful and complex teamwork among muscles Individual muscles are not represented in the centers or central pathways of the spinal cord and brain It is movements, not muscles, which are represented in the central nervous system In willing or desiring a movement, we think in terms of movements, not muscles, reflex and unconscious movements are initiated in an analogous way

KINDS OF MUSCULAR TEAM WORK

Just as a football team may employ several kinds of offensive formations and play patterns according to the game situation or the alignment of the defensive team, there are various modes of patterned action among muscles, according to the situation and the desired result A few of these kinds of muscular team work are described below

Postures A posture is a position or a stance There are obviously an infinite number of postures and many of them are important in sports and work, in physical education and in therapy The maintenance of posture often involves static contraction of fixator musculature, continued steadily for the duration of the pose More often, a posture involves a balancing mechanism, characterized by simultaneous contraction of antagonistic muscles usually at a low level of force In this state of unstable equilibrium the relative force of the contractions in the antagonistic muscle groups is constantly fluctuating The minute tendency of a body part to fall off balance is counteracted by contraction of one muscle group usually resulting in a slight overcompensation which in turn results in decreased contraction of that group together with increased contraction of the antagonistic muscle group In habitually maintained postures which are controlled at an essentially subconscious level, the stretch reflex may be the dominant mechanism in maintaining balance position Such reciprocating stretch reflexes, or their more obvious voluntary equivalents cause a slight swaying which is often so small as to be unnoticeable unless monitored by some measuring device for recording fine movements Finally it should be mentioned that some postures or aspects of posture can be maintained by the hyperextension of joints, so that further movement is prevented by the tightness of ligaments or by the occlusion of skeletal parts In this instance no muscular contraction at all may be necessary An example is the locking of the knee joint in stationary standing

Maximum Force Impulse Movements Where continued force throughout the total range of movement is required such as is the case when lifting a heavy weight or when not only continued force but maximum speed as well is necessary a situation exemplified by the sprint start, the muscles which supply the needed force contract at or near their maximum throughout the entire range of movement Any undesirable or opposing force such as the tone of antagonistic muscles is reduced to a minimum

Slow Tension Movements. Where great accuracy and steadiness but not

force, speed or great range are required, such as writing or repairing a watch the principal movers and the antagonists as well contract Motion is achieved when there is a slight difference in the amount of force exerted by one set of muscles compared to the other Movements produced in this manner are necessarily weak and slow because the effective force is the difference between the two opposing forces This net difference can be so small that the net force represented may be that exerted by a very few fibers Such movements are however under good control because any deviation instantly meets resistance When we attempt to hold some instrument as steadily as possible the forces exerted by the moving muscles and the antagonistic muscles are balanced First one group and then the other exerts a very slight amount of excess force This alternate domination of opposing muscle groups produces a condition of dynamic equilibrium known as *tremor* Our ability to reduce the magnitude *of the differences of force exerted by the two opposing groups is the limiting* factor of steadiness It is also the limiting factor in the delicacy of movement the magnitude of which is dependent upon the smallest difference of force physiologically possible to achieve

Rapid Tension Movements Movements are the same in principle except that the difference in force exerted by the movers over the antagonists is relatively large Because of the relatively large net difference in force the resultant movement is executed with more force and speed but nevertheless is still partly under the influence of the antagonistic group

Ballistic Movement Ballistic movement is exemplified by striking with a bat at a ball The movement is initiated by vigorous contraction of the prime movers and simultaneous relaxation of the antagonists The prime movers may also relax once the moving part reaches a high velocity and we rely upon its momentum to complete the action Momentum of the moving part may be checked by passive resistance offered by ligaments or opposing muscle groups, or by contraction of the antagonists which may occur toward the *end* of the movement

Oscillating Movements Oscillating movements such as shaking an object with the hand or arm are rapid tension movements which are quickly reversed at the end of each excursion The maximum possible speed of such alternating movement is highly subject to motor learning and is also dependent upon the weight or inertia of the moving parts and upon the strength of the active muscles

According to Amar [22] the following ' maximum rhythms ' have been estab lished for movements of the various segments of the upper extremity

Shoulder	5–6	Movements per second
Elbow	8–9	Movements per second
Forearm	3–4	Flexions per second
Wrist	10–11	Movements per second
Fingers	8–9	Strokes per second

Flexions are said to be faster than extensions [23] There appears to be no corre lation between power and velocity of movement and various anthropometric measurements [24,25] nor do individuals with a fast reaction time of the arms necessarily have a correspondingly fast reaction time of the legs [26] Apparently there is no general speed ability [27,28] but the maximum rate of high speed

movement may depend upon some intrinsic physiological property of the reflex circuit [29] The limiting factor may be the speed with which excitation and inhibition can be made to alternate in the central nervous system [30]

KINDS OF MUSCULAR CONTRACTION

In kinesiology the term *contraction* refers to the development of tension within a muscle It does not necessarily infer that any shortening of the muscle takes place

Static Contraction When a muscle develops tension which is insufficient to move a body part against a given resistance it is said to be in *static contraction* The length of the muscle remains unchanged Examples occur when an attempt is made to lift an immovable object, or when an object is held stationary Physiologists often refer to static contraction as *isometric contraction* (See Chapter 4 p 79)

Concentric Contraction When a muscle develops tension sufficient to overcome a resistance so that the muscle actually shortens and moves a body part in spite of a given resistance it is said to be in *concentric contraction* For example the biceps brachii muscle contracts concentrically when a glass of water is lifted from a table toward the mouth In this case the resistance is the weight of the arm and the glass of water, and the source of resistance is the force of gravity and inertia

Eccentric Contraction When a given resistance overcomes the muscle tension so that the muscle actually lengthens the muscle is said to be in *eccentric contraction* Although developing tension (contracting) the muscle is overpowered by the resistance For example when a glass of water is returned from the mouth to the table the biceps brachii muscle contracts eccentrically Actually of course, muscular contraction is not essential in this instance If the muscles were simply relaxed gravity would extend the elbow joint and lower the glass albeit with unwanted and disastrous consequences Still another way of getting the glass to the table would be to contract the triceps brachii muscle concentrically thus adding to gravitational force and extending the elbow with great vigor Such an action might be appropriate in driving nails with a hammer but not in the example cited

Both concentric and eccentric contraction are known to physiologists as *isotonic* contraction

The identification of eccentric contraction is a persistent and crucial problem in exercise analysis In performing floor pushups it is clear that the up phase involves elbow extension and shoulder girdle abduction The resistance is gravitational force the weight of the body which tends to flex the elbow and adduct the shoulder girdle Therefore, the elbow extensors and the shoulder girdle abductors must contract concentrically, overcoming the force of gravity to perform the movement When analyzing the down phase of pushups beginning students do not always find the problem so simple *It is easy* to see that elbow flexion and shoulder girdle adduction takes place and it is tempting to believe that the elbow flexors and shoulder girdle adductors are contracting concentrically Such is not the case *Gravity* is quite sufficient to energize the movement if muscle force were added to it, the body would hit the floor hard enough to cause injury Instead, the elbow extensors and the shoulder girdle abductors must develop enough tension to modify the gravita

force, speed or great range are required such as writing or repairing a watch, the principal movers and the antagonists as well contract Motion is achieved when there is a slight difference in the amount of force exerted by one set of muscles compared to the other Movements produced in this manner are necessarily weak and slow because the effective force is the difference between the two opposing forces This net difference can be so small that the net force represented may be that exerted by a very few fibers Such movements are, however, under good control because any deviation instantly meets resistance When we attempt to hold some instrument as steadily as possible the forces exerted by the moving muscles and the antagonistic muscles are balanced First one group and then the other exerts a very slight amount of excess force This alternate domination of opposing muscle groups produces a condition of dynamic equilibrium known as *tremor* Our ability to reduce the magnitude of the differences of force exerted by the two opposing groups is the limiting factor of steadiness It is also the limiting factor in the delicacy of movement the magnitude of which is dependent upon the smallest difference of force physiologically possible to achieve

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tional force and lower the body to the floor at a reasonable speed In doing pushups the same muscles act throughout the exercise, contracting concentrically on the up phase statically during the momentary held position between phases and eccentrically during the down phase

During World War II a writer not professionally trained in physical education advocated the following exercise for conditioning the abdominal muscles From a position of standing with arms raised overhead, bend forward downward and touch the toes on count 1, return to starting position on count 2 The abdominal muscles may receive some passive squeezing during this exercise but it is obvious that the spinal extensors are the active muscles contracting eccentrically on the way down and concentrically on the way up The abdominal muscles remain relaxed during both motions

In exercise analysis it is always necessary to consider the external forces which may be operative The most important of these is gravity, but it is by no means the only one In sports and work there are countless other forces acting in various directions, which must be considered Muscular forces exerted by opponents in such contact sports as football and wrestling the force of moving objects such as balls and other sports implements the force of waves tides, and currents in swimming—all these must be carefully evaluated in the analysis of muscular action of bodily movement

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demonstrated It has been suggested that the current causes a chemical substance to diffuse inward, but it has been objected that the time between a stimulus and the active state is too short for this explanation to be satisfactory It is believed that the delay between stimulus and contraction is due to the delay in the release of the chemical energy necessary for contraction although recent studies have indicated that the chemical reactions may be well advanced before any detectable shortening begins [5] Similarly, the loss of tension at higher speeds is now believed to be related to the rate at which chemical energy is made available, and not to the viscous resistance of the muscle

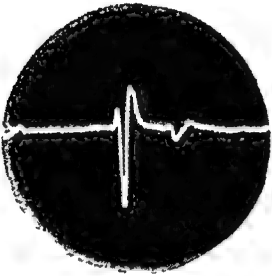


FIG 16 —Normal Motor Unit wave showing large characteristic negative phase both preceded and followed by smaller positive phases (Meditron Co)

Chemistry of Muscular Contraction Muscle chemistry and the energy exchanges of muscle metabolism are largely beyond the scope of this book Individuals desiring detailed information on these subjects are referred to the various texts on the physiology of activity However students of kinesiology need at least an elementary understanding of the processes which enable the muscles to contract and thus move the body The highly simplified explanation presented here is subject to several reservations First research in this field is progressing so rapidly that radical revisions of its theories may appear at any time Second serious students must recognize the necessity of mastering advanced biochemistry before being able to comprehend the technical literature of the topic Third any brief presentation of the topic will necessarily oversimplify or omit much technical data

The ATP Cycle Physiologists are not sure what substance shortens upon stimulation of a muscle nor why it does so It is certain that the contraction of muscle consumes energy Extensive research has been done to determine how this energy is supplied and how the several kinds of fatigue occur Until recently it has been almost universally believed that the energy for contraction comes mainly perhaps wholly from the breakdown of a substance called *adenosine triphosphate* or *ATP* ATP is known to be a rich storehouse

Chapter 4

The Physiology of Muscular Contraction

Action Potential The use of microelectrodes has shown that when a neuron is at equilibrium the outside of the nerve membrane is positively charged compared with the inside Sodium ions are concentrated on the outside of the fiber potassium ions on the inside When a nerve is excited an *action potential* is generated (Fig 16) There is a sudden reduction of the positive charge producing the *spike potential* which lasts less than 0 5 msec and attains an amplitude of approximately 130 m v There is a change in the membrane potential of the fiber Sodium ions flow inward and potassium ions later flow outward Sherrington referred to the nerve impulses as fleeting and self mending leaks which move along the skin of the nerve thread [1] Within milliseconds the return of the polarization of the nerve to normal is indicated by the *negative after potential* which lasts 15 to 20 msec It is believed by some students that the size of a muscular contraction is related to the size of the negative after potential [2] The membrane then becomes hyperpolarized as indicated by the *positive after potential* which may last from 80 msec to over a second and resting conditions are restored The duration of action potentials in persons twenty to forty years of age shows no significant differences between individuals or sexes but becomes prolonged with age or low muscle temperature thus leading to an increased reflex time

End Plate Potential The electrical disturbance proceeds down the nerve until it arrives at a myoneural junction where it causes *acetylcholine* to be liberated from the nerve terminals This substance depolarizes the end plate of the muscle fiber and gives rise to the *end plate potential* This in turn alters the potential of the muscle membrane and a muscle impulse is set up [3] There is strong evidence that the function of the muscle membrane is to receive the stimulus from the nerve and transmit it to the contractile substance possibly through the Z bands but how excitation is passed from the surface to the interior is unknown In states with either a low or high ratio of intracellular to extracellular potassium in the muscles marked weakness may be observed due in part to impaired neuro muscular transmission [4]

Direct spread of electrical current from nerve to muscle has never been

to more than a few tenths of 1 per cent, muscle pain occurs and contraction ceases This is what happens under anaerobic conditions, that is, when either cessation of breathing or impeded circulation prevents the supplying of oxygen to the muscles This sort of fatigue is perhaps the most common limiting factor to muscular activity, and it should be noted that it is a direct poisoning (perhaps the result of increased acidity) rather than an interruption of the energy supply It can be demonstrated in the classroom by having a subject open and close his fist repeatedly, and then cutting off the blood supply (oxygen supply) by tightening a flat tourniquet or blood pressure cuff on the upper arm In work and sports strong static contraction of a muscle may be sufficient to impede circulation in a similar manner, tight garters, adhesive tape, or restrictive clothing may cause the same phenomenon

In aerobic work the conditions are quite different An adequate oxygen supply results in the oxidation of about one fifth of the lactic acid present

$$L + O_2 \rightarrow H_2O + CO_2$$

Part of the lactic acid is oxidized to produce water and carbon dioxide, which are in turn excreted through the lungs if produced in moderate quantities Furthermore the energy released by the oxidation of one fifth of the lactic acid is sufficient to energize a re synthesis of the remaining four fifths of the lactic acid back to glycogen—a sort of supercharging effect which conserves the available fuel This completes the Glycogen Lactic Acid Cycle but it should be noted that this cycle unlike the ATP and PC Cycles, is incomplete, for it depends upon introduction of glycogen and oxygen from outside the body In spite of the supercharging effect, some of the glycogen is eventually oxidized into carbon dioxide and water which is excreted and thus eliminated

Figure 17 is a schematic summary of the chemistry of muscular metabolism In it the three cycles are identified with phosphate participating in all of them The imperfection of the Glycogen Lactic Acid Cycle is indicated by the diagrammatic provision for supply of fuels from and excretion of waste products to the outside

While this scheme of things appears satisfactorily to explain the working of muscles Mommaerts[6] has shown a single muscle twitch may take place without a demonstrable breakdown of either ATP or PC Buchthal Svensmark and Rosenfalk[7] noted that there was no direct evidence for the break down of ATP during the contraction of non fatigued muscle *in vivo* and commented that to establish if or when ATP is dephosphorylated in the contraction cycle seems to be an essential link in bridging the gap between the chemical and mechanical processes in muscle What effect these findings will have on the current theories of muscle contraction is a matter of conjecture

Chemical Limitations of Muscular Performance Muscular work may be limited in a variety of ways these in effect are kinds of fatigue A few kinds of fatigue may be understood in terms of the foregoing simplified version of muscle chemistry others not considered here have a locus in various parts of the nervous system from the myo neural junction back up to the higher levels of the cerebral cortex

Oxidation is the most important mechanism for preventing the kind of

of energy When it is triggered by some aspect of muscle stimulation it breaks down into *adenosine diphosphate* (ADP) and *free phosphate* (P)

$$ATP \rightarrow ADP + P,$$

yielding great energy for the shortening of muscle Because of depletion of ATP the duration of muscular contraction would be short were it not for the fact that the reaction is reversible Phosphate and ADP can be re synthesized to replenish the store of ATP

$$P + ADP \rightarrow ATP$$

This reversible reaction constitutes the ATP Cycle accounting for continued muscular work by a repeated breakdown and re synthesis of ATP However just as the breakdown of ATP yields energy so energy is required for its re synthesis and another source of energy must be sought in order to explain this seeming perpetual motion

The Phospho-creatine Cycle A second energy rich substance, phospho creatine (PC) is also found in muscle fluids It can break down into creatine (C) and free phosphate (P)

$$PC \rightarrow C + P$$

yielding energy for the re synthesis of ATP The situation is now analogous to that encountered with the ATP Cycle The phospho creatine would soon be depleted and muscular work would have to cease were it not possible to reverse the reaction and re synthesize the substance

$$C + P \rightarrow PC$$

Again energy is needed and since the breakdown energy of PC was consumed in re synthesizing ATP, yet another source of energy is required for the re synthesis of PC

The Glycogen Lactic Acid Cycle The digestion of carbohydrate foodstuffs (and to a lesser extent other foodstuffs) results in a simple sugar like end product called glucose Glucose undergoes a slight chemical transformation and becomes glycogen (G) as it enters either of its two principal storehouses in the body the liver and the muscles Liver glycogen is readily mobilized back to its transportation form glucose in order to be carried through the blood to replenish the muscle glycogen (Well trained muscles contain significantly greater amounts of glycogen than do un trained muscles when the body is at rest)

Muscle glycogen can undergo chemical breakdown to produce *lactic acid* (L) This transformation of glycogen to lactic acid is called glycolysis and is not a single direct reaction but rather a complex chain of reactions involving in its intermediate phases first the uptake of phosphate (*phosphorylation*) and then its release During glycolysis energy is released and it is this energy which becomes available for the re synthesis of phospho creatine thus enabling completion of the Phospho creatine Cycle Glycolysis (with phosphorylation and other intermediate phases omitted) is symbolized as follows

$$G \rightarrow L$$

Lactic acid is a virtual poison in the muscular economy If it accumulates

during exercise After exercise when further oxygen is available, the chemical reactions of buffering may be reversed and the re freeing of lactic acid can be met by the oxidative process during post exercise recovery Training over a period of weeks or months will greatly increase the amount of blood buffers (collectively referred to as the *alkaline reserve* of the body) but the ingestion of alkaline substances in attempts to build up the alkaline reserve beyond the regular physiological capacity has proven fruitless [8]

If only one part of the body is active, the locally produced lactic acid may be diffused by the blood into inactive parts of the body, thus preventing the build up of acidity in any one area This explains why fatigue may be felt in the arms following vigorous exercise of the legs Also, small amounts of lactic acid can be excreted in the urine and the heart muscle is unique in being able to utilize lactic acid as a fuel

An entirely different kind of fatigue is caused by the depletion of the stores of glycogen Since the liver contains large amounts of reserve glycogen, only the very strenuous and greatly prolonged activities, such as marathon running and endurance swimming are capable of creating this kind of fatigue If players are conditioned to their sport it is virtually impossible to exhaust their glycogen reserves within normal time limits of most sports In these sports, fatigue is of some other sort The so called ' quick energy ' which is supposedly supplied by a candy bar, soft drink or glucose tablet is almost entirely psychological Additionally, such concentrated doses of sugar may irritate an enzymatic reaction which encourages the storage of glycogen rather than its mobilization thus defeating the purpose of the feeding [9] Marathon runners and channel swimmers, on the other hand often perform better if fortified by honey sweetened tea, or other sugar supply during the later phases of their grueling performances [10]

Muscle Chemistry During Rest Athletes train by alternating periods of strenuous activity with rest pauses, the latter being fully as important as the former Among the chemical changes in the muscles during rest are the following

(1) ATP and Phospho creatine are completely re synthesized effectively reconstituting the energy rich substances at the site of contraction

(2) All residual lactic acid including that which has diffused into inactive parts of the body is oxidized or re synthesized

(3) Muscle glycogen stores are replenished and under the stimulus of a training regimen, may be increased

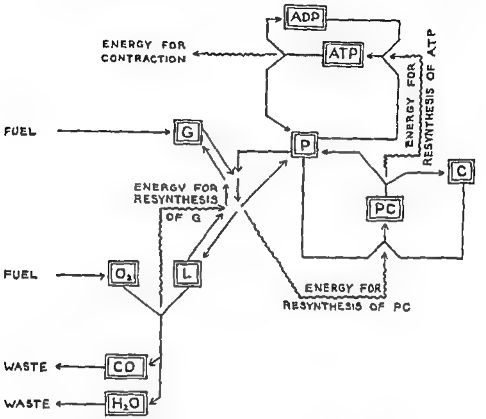
(4) Liver glycogen stores are replenished and increased, provided that adequate carbohydrate food is ingested and digested

(5) The end products of the neutralizing activity of the body buffers undergo reverse chemical reactions freeing lactic acid and other acids for oxidation or elimination

(6) Muscle protein and other tissue proteins which were destroyed during the activity are replaced Moderate to severe activity usually results not only in repair of damaged tissues but also in further growth strengthening or toughening of the protein structures

Mechanics of Muscular Contraction The physical rearrangements which take place during muscle contraction are as controversial as are the chemical processes involved Many students have reported that during contraction the

fatigue due to accumulation of lactic acid Its efficiency depends upon (1) the development of cardio respiratory endurance through training (2) avoidance of tight clothing bandages, and work or sports implements (3) avoidance of continuously held static positions by frequent changes of position and other means (4) avoidance of breath holding, which may result from hypertension in chest and arm musculature (related to tying up in running) from ex



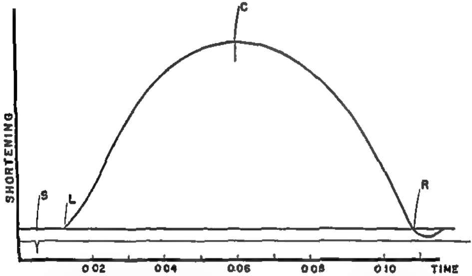
———→	Chemical reaction	C —	Creatine
~~→	Energy exchange	G —	Glycogen
ATP —	Adenosine Triphosphate	L —	Lactic acid
ADP —	Adenosine Diphosphate	O_2 —	Oxygen
P —	Phosphate	CO_2 —	Carbon dioxide
PC —	Phospho creatine	H_2O —	Water

FIG 17 —Schematic summary of the chemistry of muscular contraction For the sake of clarity many intermediate steps have been omitted (Douglas)

treme exertion or from abnormal breathing habits (5) use of oxygen masks self contained underwater breathing apparatus (SCUBA) or other devices when working under water in the thin air of high altitudes or in oxygen depleted air and (6) deliberately adjusting the exercise so that it involves a rhythmical alternate contraction and relaxation of large muscle groups so as to stimulate circulation and the return of venous blood to the heart

Eventually lactic acid must be oxidized but it may be dealt with temporarily in some other ways The *buffers* of the blood which are substances capable of neutralizing acids can neutralize great quantities of lactic acid

mulus is about 0.01 second It then takes the muscle about 0.04 second to contract and about 0.05 second for the subsequent relaxation After an impulse has been produced there is an *absolute refractory period* lasting approximately 0.4 to 1.0 milliseconds during which a nerve fiber will not respond to stimulation This is followed by a *relative refractory period* of approximately 3 milliseconds during which the fiber regains its irritability and will respond to a relatively intense stimulus It has been suggested that the absolute refractory period corresponds with the front part of the action potential, while the relative refractory period corresponds with the back half During the negative after potential a stimulus of less than normal strength can excite the neuron during the positive after potential a larger than normal stimulus is required to excite the neuron



CURVE FORM OF A TYPICAL SINGLE TWITCH
S-L LATENT PERIOD
L-C CONTRACTION PERIOD
C-R RELAXATION PERIOD

FIG 18

The conducting system of striated muscle differs only quantitatively from that of nerve The same sequence of spike potential and negative and positive after potentials is found Adrian and Bronk[15] have commented on the remarkable fact that the discharge of a motor nerve cell can hardly be distinguished from the discharge of a sense organ although there are major differences in their structural factors

Treppe When a muscle is stimulated in such a way that complete single twitches rapidly follow each other the first few contractions progressively increase in height This is known as *treppe* or the staircase effect This successive increase in the extent of the contraction has led some authors to cite it as the mechanism responsible for the benefits of warm up in sports Karpovich[16] has pointed out the fallacy in this reasoning noting that treppe occurs (1) only in well rested muscle and (2) only as the result of spaced single

A bands tend to remain relatively constant in length, while the I bands shorten as many others have stated that the A band shortens and the I bands lengthen slightly on contraction [11] Some of the electron microscopy studies indicate that when a muscle shortens the diameter of the myofibrils in the A band increases in proportion to the shortening Both the A band and the I band decrease in width [12] a finding which would appear consistent with Fenn s view that both the A and I bands have contractile power although the former are possibly the stronger Classically it has been believed that the myosin molecules in a muscle are in a somewhat folded condition during the resting state When stretched the molecular structure becomes more elongated, when contracted the amount of folding increases An alternative theory is that they are in a helical configuration and stretch and contract like a spring Shortening within the physiological range is assumed to represent a folding up or a change in the helical arrangement of the sub units of the myofilaments The most recent interpretation is that when changes occur in the length of a muscle the primary and secondary filaments slide past each other *i e* the muscle shortens but its filaments do not (See p 53) One objection to this suggestion is that apparently it does not provide for more than 50 per cent of the amount of shortening which may actually take place

The problem has been well summarized by Betts

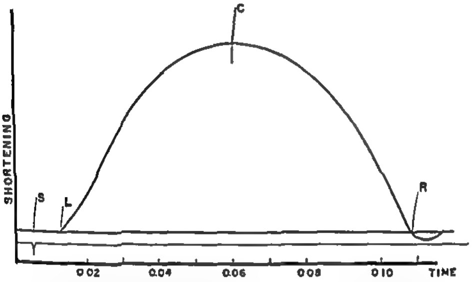
> for muscle to do work chemical energy must ultimately be transformed into mechanical work but how and at what stage this transformation is accomplished remains controversial [12]

All or None Law When an individual muscle fiber is stimulated under laboratory conditions it contracts maximally or not at all This is the so called all or none principle In intact muscle however an increased stimulus results in an increased mechanical response This has been used as a basis for arguments that the all or none law does not apply to striated muscle However any tissue having a definite threshold for excitation and known to be refractory after excitation must be considered to behave according to this principle

Nevertheless there are serious difficulties in interpreting the evidence from skeletal muscle studies [13] Individual striated muscle fibers respond differently Their response is a complex series of events liable to vary considerably according to conditions existing in the fibers A weak stimulus excites only the most irritable fibers whereas a strong stimulus may affect even the least irritable fibers The more fibers are excited the greater the force of the contraction It has been postulated that one of the benefits of training with near maximal weights in progressive resistance exercise is that this brings some of the high threshold neurons within the orbit of voluntary activity [14]

Twitch When studying muscular contraction physiologists use what is known as a muscle nerve preparation This usually consists of a freshly excised gastrocnemius of a frog or the tibialis anticus of a dog cat or rabbit together with its motor nerve When an electrical stimulus of sufficient size is applied to the motor nerve the muscle responds with a spasmodic contraction known as a *muscle twitch* Such preparations have been very useful for studying the events in muscle contraction By their use it has been demonstrated that there is a delay between the time the stimulus is applied and a response can be detected This is known as the *latent period* and in a frog gastrocne

mius is about 0 01 second It then takes the muscle about 0 04 second to contract and about 0 05 second for the subsequent relaxation After an impulse has been produced there is an *absolute refractory period* lasting approximately 0 4 to 1 0 milliseconds, during which a nerve fiber will not respond to stimulation This is followed by a *relative refractory period* of approximately 3 milliseconds during which the fiber regains its irritability and will respond to a relatively intense stimulus It has been suggested that the absolute refractory period corresponds with the front part of the action potential while the relative refractory period corresponds with the back half During the negative after potential a stimulus of less than normal strength can excite the neuron during the positive after potential a larger than normal stimulus is required to excite the neuron



CURVE FORM OF A TYPICAL SINGLE TWITCH
S L = LATENT PERIOD
L C CONTRACTION PERIOD
C-R = RELAXATION PERIOD

FIG 18

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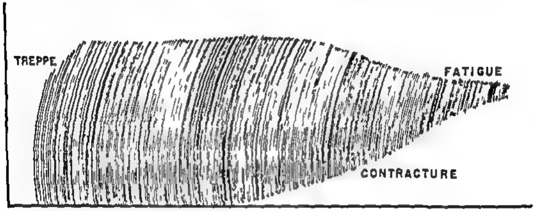
nerve impulses In the intact muscle even the briefest stimulation consists of a volley of closely spaced nerve impulses Treppe would take place in a fraction of a second the first time the muscle is used, whereas warm up benefits require a prolonged preliminary activity

Wave Summation An adequate stimulus produces a muscle contraction which lasts for a definite period If a second stimulus is received while the muscle is still contracted, its shortening and tension is increased The force finally exerted may be three times as great as that afforded by a series of single twitches

Tetanus If successive stimuli are administered very rapidly, no time is allowed for the muscle to relax This fusion of superimposed twitches is known as *tetanus* or *tetanic contraction* It is the normal type of voluntary muscular contraction and may be maintained until fatigue intervenes (Figure 19)



TYPICAL CURVE OF MUSCLE FATIGUED
BY REPEATED CONTRACTIONS

FIG 19 —Summation of adequate stimuli and tetanus

Tetanic contraction in voluntary muscle is maintained by a series of nerve impulses which range from 5 to 50 or more a second in each nerve fiber [15] Cooper and Eccles[17] studied the contraction time (interval between onset of electrical response and attainment of maximum tension) in an isometric twitch the frequency of the rhythm when each successive stimulus is separated by the contraction time characteristic of the muscle and the number of stimuli required per second to produce complete mechanical fusion of the contractions in a pale mixed and red muscle Their findings are given in Table 5 From this table it is seen that pale fibers display a short latent period but require a high rate of discharge to maintain tetanus whereas the opposite is true of red muscles

Gradations in the speed and force of contraction of voluntary muscle depend upon the number of motor units in action and the frequency of response in the individual units The frequency of response increases quite evenly with gradually increasing effort, whereas the addition of each new motor unit represents a discrete step It appears that the change in frequency

is the more delicate method of grading the strength of a contraction, while the accession of units is probably a quicker and more potent factor Under experimental conditions the strongest voluntary effort does not drive motor units at frequencies above 50 per second It is possible that under the stimulus of an emergency or athletic competition this rate becomes increased [17]

Under certain conditions of disease or injury either cardiac muscle or skeletal muscle may display *fibrillation*, a rapid, uncoordinated, rhythmical twitching of individual muscle fibers that accompanies atrophy of muscle following denervation or certain other injury *Fasciculation* is a spontaneous twitching of bundles of muscle fiber resulting from single impulses in motor units It may be produced by irritations of the cell bodies of the motor neurons as in poliomyelitis

The contraction of a muscle as a whole is smooth because the jerky responses of the motor units are out of phase with each other and there is a continuous alternation of units If the activity of the units becomes synchronous and the contractions alternately and rhythmically appear in muscle

TABLE 5 —Contraction Time and Stimulation Requirements in Mammalian Muscle

Muscle	*Contraction Time*	*Rate of Stimulus for Twitches*	*Rate of Stimulus for Tetanus*
	In Seconds	*Per Sec*	*Per Sec*
Internal rectus	0075	133	350
Gastrocnemius	025	25 6	100
Soleus	049– 120	8 3–10 6	31–33

groups and their antagonists, *tremor* results If they appear simultaneously in both a muscle group and its antagonists *rigidity* is seen Both are characteristic of paralysis agitans [18] Coordinated grouping of the discharge of muscle units results in the gross tremor of *shivering* [19]

Discharge rates in trained men are said to be slower and more regular than in untrained men presumably due to afferent impulses from the proprioceptors producing a functional rearrangement in the cerebral cortex [20]

The refractory period of cardiac muscle is so long that the muscle becomes almost completely relaxed before a second stimulus can become effective For this reason tetanus cannot develop in normal cardiac muscle and the heart does not display fatigue in the same manner that skeletal muscle does

Contracture The term contracture is used in two different ways When a normal muscle becomes fatigued the force and amplitude of the contractions decrease and complete relaxation between stimuli will not take place A residue of activity may be indicated by the presence of tremor This condition may be observed when a runner ties up when fatigue sets in

Contracture is also used to indicate abnormal responses of muscle which result from an agent acting directly upon the contractile mechanism without involving an action potential This indicates that the contractile mechanism

nerve impulses In the intact muscle, even the briefest stimulation consists of a volley of closely spaced nerve impulses Treppe would take place in a fraction of a second the first time the muscle is used, whereas warm up benefits require a prolonged preliminary activity

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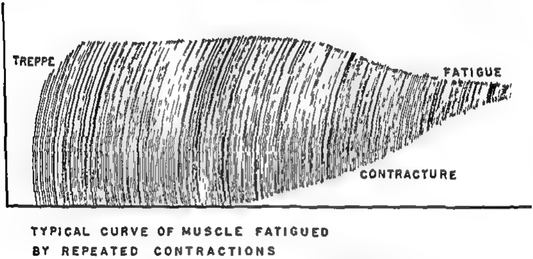

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Only muscles acting on a single joint can be assumed to be true antagonists Muscles acting on more than one joint may at times act as antagonists and at other times as synergists The rectus femoris normally acts as an antagonist to the hamstrings, but if the hip and knee are flexed simultaneously, the rectus femoris acts synergistically with them In some muscles one part may act as an antagonist and another part as a synergist

As an agonist goes into the final range of contraction, it begins to cause proprioceptive stimulation through stretch reflexes of the antagonist muscle The resulting contraction of the antagonist then offers resistance to the final phase of movement of the agonist The angle at which this occurs varies with the joint and the muscles involved

It has been possible to demonstrate reciprocal innervation in the human in unresisted voluntary movement, in reflex movements such as the knee jerk, and in cases of spasticity, a condition which leads to a structural shortening of the muscles involved Electrical stimulation of muscles antagonistic to those in spasm has been found to result in relaxation of the spastic muscles In normal voluntary movement co contraction seems to be the rule rather than the exception and satisfactory evidence that reciprocal innervation plays the part usually assigned to it by kinesiologists is lacking [26]

Barnett and Harding[27] suggest that antagonistic muscles behave in at least three distinct ways

1 When external resistance is so great that the joint cannot move the antagonists relax

2 When the muscles are acting against moderate resistance, the antagonists become active to decelerate the movement and their electrical activity is proportional to the rate at which the joint is moving

3 When there is no external resistance to be overcome and the limb must move with great precision there is no inverse degree of activity in the two opposing groups

Isometric Tension When force is exerted by a muscle against an object which it cannot move the muscle remains at the same length but technically accomplishes no work The energy which would normally be displayed as mechanical work is dissipated as heat In such a case the muscle is said to develop *isometric tension* Actually no muscle action is perfectly isometric Even under the most rigid conditions the contractile elements shorten by 5 to 10 per cent of their length by stretching the elastic components There is good evidence that the muscle fibers are not of uniform strength some of the heat produced may result from the extending of the weaker fibers by the stronger ones It has been suggested[28] that the development of isometric tension may be analyzed as a gradual internal shortening of a contractile substance of the muscle against an elastic, passively extending portion Posture is largely maintained by isometric contractions of certain muscles of the back and legs where muscular tension is required to offset the effects of gravity upon the body It is also employed for muscle setting exercises in physical medicine

Isotonic Contraction When a muscle is able to move a load work is accomplished and the muscle is said to have performed an *isotonic contraction* With a given stimulus a muscle develops more energy when doing isotonic work than when developing isometric tension This is known as the *Fenn effect* and

is itself contractile and that the action potential is to be regarded as something superimposed upon it to make its response more certain Muscles in this type of contracture readily pass into irreversible rigor [21]

Cramps During vigorous exercise or during sleep healthy persons may experience an involuntary, sustained painful contraction of skeletal muscle termed a cramp It is uncertain whether these have their origin in muscle, peripheral nerve, or the spinal cord For experimental purposes they can be voluntarily induced by a maximum voluntary effort while the muscle is in a shortened position The pattern of the action potentials recorded electromyographically indicates that they are due to excitation of most of the muscle fibers in a given motor unit suggesting that the cramp must be explained in terms of motor unit activity originating in the central nervous system The pain seems to be proportional to the total number of active units [22]

There is evidence that the onset of cramps during vigorous physical activities results from a loss of sodium and chloride in the serum due to sweating [23] but the actual change in the muscle or nerve is unknown Hypertrophied muscles appear more liable to cramping than are normal muscles but physiologically hypertrophy is not associated with any known change in excitability or EMG pattern and no relief is afforded by the ingestion of sodium chloride [24]

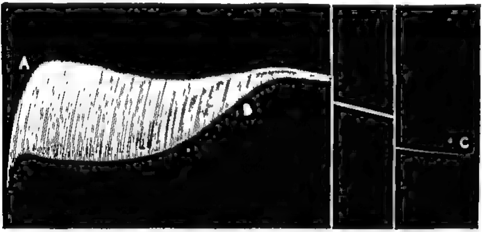

FIG 20—Effects of repeated stimulation of frog muscle A Treppe B Contracture C Fatigue (From Francis Knowlton and Tuttle Textbook of Anatomy and Physiology courtesy of The C V Mosby Co)

Co contraction and Reciprocal Innervation Sherrington who worked with decerebrate or anesthesized animals in whom voluntary control was abolished and only reflex movement was present observed that contraction of a muscle produced by proprioceptive action a central inhibitory effect in its antagonist This he labelled *reciprocal innervation* He also noted that antagonists may be in contraction concurrently which he attributed to *double reciprocal innervation* As early as 1935 however Tilney and Pike found that under normal conditions they were unable to observe Sherrington s phenomena and concluded that muscular coordination depends primarily on the synchronous co contractive relationship in the antagonist muscle groups [25]

gm through 2 cm of distance, doing the same amount of work as before If the above process is repeated, the muscle can now pull with a force of 200 gm through 4 cm of distance The number of variations in the arrangement can be multiplied indefinitely, with the same amount of work being done in each case

Negative Work In the case of an eccentric or lengthening contraction, as occurs when lowering a heavy weight slowly or when walking down stairs, no external work is being done according to the above definition In such cases instead of work being done by the muscles on the weight, it is done by the weight on the muscles, and is referred to as negative work Its numerical

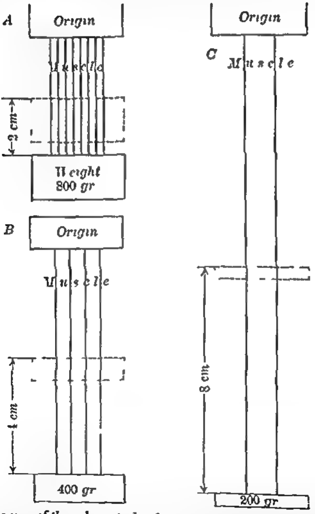

FIG 21 —Diagram of three longitudinal muscles showing how number and length of fibers affect power and extent of movement *A* has 800 fibers 4 cm long *B* has 400 fibers 8 cm long and *C* has 200 fibers 16 cm long Arrows indicate extent of contraction

value is calculated exactly as in the above formula if a 100 pound weight is lowered slowly through 3 feet the work done is -300 foot pounds

Static Work Still another difficulty arises however Muscles which are in a state of tonic contraction to overcome the force of gravity are obviously

is typical of most active movements of the limbs in work or sport However, no contraction is perfectly isotonic since a normal muscle is always shorter than the distance between its origin and insertion and hence is always subject to some degree of stretching During the process of contraction a muscle gains energy but this is offset by the fact that its antagonist loses' energy At a constant velocity of shortening or lengthening the electrical activity has been found to be directly proportional to the tension, at a constant tension, the electrical activity increases linearly with the velocity of the shortening [29]

In isotonic contraction it appears probable that the shortening first takes place mainly in the I bands If the amount of shortening is great, the I bands disappear and it is believed that the A bands must fold in some way [30] During isometric contractions the length of the A and I bands apparently remains unchanged [31] The evidence regarding the deformation of the A and I bands under conditions of stretch is thoroughly confusing and no definite statement concerning it can be made In spite of the observed differences, the amount of tension which may be developed by a single isometric contraction of the elbow flexors and the amount of weight which may be moved in a single isotonic flexion do not appear to be appreciably different [32]

As a rule the tendon is stronger than the muscle, and does not rupture when a limb is subjected to severe strain Loads great enough to produce lesions usually pull the tendon insertion away rupture the muscle belly separate the muscle tendinous junction cause the muscle origin to pull out, or fracture the bones [33]

Work Done By Muscular Contraction The amount of work done by a contracting muscle is a combination of two elements of equal importance The amount of force used and the distance of the movement Stated mathematically the amount of work done is the product of the force multiplied by the distance ($W = F \times d$) One unit of work is the amount involved in exerting one unit of force through one unit of distance, regardless of what these units are so that work may be expressed in gram centimeters foot pounds kilogram meters foot tons or any other appropriate combinations, according to the units of force and distance employed

The force that a muscle can exert depends on the number and size of its fibers the distance through which it can contract depends on the length of its fibers It follows from the first that the strength of skeletal muscles is proportional to their muscular cross section Calculations of the strength of muscle tissue per square centimeter of cross fiber vary from 3 6 kg[34] to 10 kg [35] It is probable that normal muscle can contract up to about 25 per cent of its relaxed state [34] Thus a longitudinal muscle that has 2 square centimeters of cross section and fibers normally 8 centimeters long could do 14 4 kilogram centimeters of work in a single contraction if the lower figure is accepted for the strength of muscle ($3\ 6 \times 2 \times 2 = 14\ 4$)

In order to illustrate how muscular structure is related to muscular work assume that a muscle has 800 fibers each 4 cm long and each able to exert a force of 1 gm (Figure 21)

Under this supposition the muscle can exert a force of 800 gm cm of work at one contraction Now suppose the muscle split lengthwise and the halves placed end to end making a muscle of exactly the same total bulk with half as many fibers twice as long (Figure 21) it can now pull with a force of 400

METHODS OF STUDYING MUSCULAR ACTION

There are at least five ways of studying a muscle to determine its action

1 Study of the conditions under which a muscle acts by the use of a mounted skelton, noticing its points of attachment direction of pull leverage, and any other points bearing upon the problem that can be discovered

2 Pulling upon the partly dissected muscles of a cadaver and noticing the resulting movements

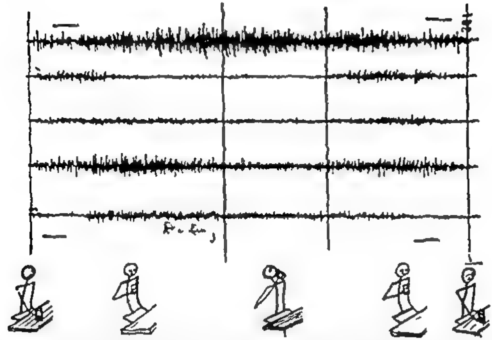

FIG 22 —Electromyograms of arm muscles during the act of drinking a glass of water Subject C Muscles recorded from top to bottom trapezius deltoid triceps biceps brachio radialis The figurines indicate the phase of the movement from left to right lifting glass drinking bringing glass down (Hirschberg courtesy of Am J Phys Med)

Both of these methods have their uses but it does not necessarily follow that the muscle action *in vivo* can be deduced from either one of them Synergistic actions cannot be determined by such methods Muscular movements usually involve groups of muscles and a muscle may work with different groups in different movements

3 Stimulation of individual muscles by electric current and noticing the resulting movements This was the method of the classic researches of Duchenne It has served greatly to increase our knowledge but may be applied only to the superficial muscles and is largely subject to the objections made to the use of the first two methods

4 The study of subjects who have lost the use of certain muscles to determine what loss of power and movement has resulted and whether any abnormal postures have been produced Studies of this kind have added

expending energy but since the load is not being moved through space technically no work is being accomplished Starr[36] has endeavored to develop a method of measurement whereby both static and dynamic work may be expressed in similar terms

Mechanical Efficiency The mechanical efficiency of a muscle is expressed as the ratio of work accomplished (W) to the total energy expended (E) according to the formula

$$ME = \frac{W}{E}$$

Hill[37] calculated that theoretically muscle efficiency was about 40 per cent, for any given activity however it is usually less than 25 per cent

Work Load The ability of a muscle to perform useful work varies greatly with the load applied A very light load does not make full use of a muscle s potentialities and uses an excessive amount of its potential energy in simply overcoming the frictional resistance of the muscle itself The internal force exerted by a muscle falls off with an increase of velocity according to an exponential law [38] If the load is very heavy, the rate of lifting may be very slow According to Hill[39] the mechanical efficiency of muscle is greatest at about 1/5th of its maximum speed In more practical terms it has been suggested that for women the most economical load appears to be about 35 per cent of the body weight A load of about 45 pounds would appear to be the optimum for continuous carriage although the average woman should be able to handle 50 pounds without strain A possible 20 per cent additional load might be allowed when the burden is compact and easily handled The recommended maximum load for men is 130 pounds, although the amount of weight that can be safely handled is so affected by constitutional type strength age, experience compactness of load and other factors that wide variations from this figure may be acceptable [40] For the average man the optimum speed for walking has been found to be about 3 5 miles hence this is the speed at which soldiers normally march

Two Joint Muscles The fact that some muscles pass over two joints of the skeleton affects their work efficiency For example, when the leg is moved forward the tensing of the rectus femoris simultaneously contributes to the flexing of the hip joint and the extending of the knee joint when the leg is moved backward the tensing of the hamstrings simultaneously contributes to the extending of the hip joint and the flexing of the knee joint When the sartorius functions efficiently it tends to flex simultaneously the hip and knee joints Thus while one muscle is accomplishing positive work at one end it is simultaneously accomplishing negative work at the other end If this work had to be accomplished by two separate muscles each would have to do positive work Since the total work done is the algebraic sum of the positive and negative work a considerable saving in energy expenditure is achieved by the two joint muscles Elftman[41] has calculated that the work of walking requires an expenditure of 2 61 horsepower by the limb muscles if only single joint muscles were used 3 97 horsepower would be required Other implications of the two joint muscles have been examined by Markee and his collaborators [42] and this subject is further discussed in Chapter 14 p 253

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materially to our knowledge of muscular action, but it is difficult to obtain a sufficient variety of subjects to study the muscles in a systematic way

5 Study of the normal living body to find what muscles contract in certain exercises and what movements call certain muscles into action This is perhaps the most practical approach to kinesiological problems Normal subjects are always available Whatever we may deduce from other methods, this one must provide the final decision, for neither observations made on a cadaver or a skeleton nor data provided by electrical stimulation experiments can tell what a muscle *will* do although they may tell what a muscle *can* do We need to learn not only what action a muscle is able to perform because of its position and opportunity, but also what, in an actual case the nervous system calls upon it to do and when it permits it to lie idle Some of Duchenne s most brilliant discoveries by means of electrical stimulation have been found to be misleading because observation of the living body shows that certain muscles which might help greatly in a movement actually never do so An example is the gluteus maximus which could participate in leg extension in walking but does not

Observations on normal subjects may be made by two quite different techniques The first and best suited to beginners is to determine the action of muscles in a given exercise by seeing or actually feeling the muscle contract This method is limited by the fact that many muscles are so situated that they cannot be observed directly and as a result dependable results cannot be obtained by it

The student with some technical background may make use of an electromyograph With this apparatus small metal disks are placed on the skin over the muscle or tiny needles are inserted directly into it These pick up the action potentials every time a muscle moved These may be amplified and shown on an oscilloscope where they may be photographed if desired A more general technique is to record the potentials on moving paper so that a permanent record of the action of the muscle throughout a given movement is made By this means the action of a number of muscles may be observed simultaneously and the student can tell at exactly which point each one comes into play and when its action ceases The primary difficulty with this method is that it cannot be used to determine the action of the deeper muscles such as the psoas iliacus

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Chapter 5

Neural Control and Motor Learning

THE NEURON AND ITS FUNCTIONS

The Neuron The structural and functional unit of the nervous system is the single nerve cell, or *neuron* (Figure 23). It consists of a nucleated *cell body* and two or more processes called *nerve fibers*. The processes may be divided into *axons* and *dendrites*. Usually there are several dendrites, which may traverse either a very long or a very short distance between the cell body and the multiple branching at their terminal *arborizations*. Dendrites serve a receptive function; they normally conduct impulses toward the cell body. Generally, a neuron has but one axon, which may be up to 3 feet long, serving to carry impulses away from the cell body and to pass the impulse along to the dendrites of other neurons. The cell bodies are located in the gray matter of the spinal cord and brain or in ganglia (collections or bunches of cell bodies) located outside of, but relatively close to, the spinal cord. Nerve fibers may be found intermingled with the cell bodies of the gray matter, or they may be arranged longitudinally in white bundles. White bundles within the spinal cord and brain are known as *tracts*, *columns*, *commissures*, and so forth; those outside the spinal cord and brain are known as *nerves*. Neurons should not be confused with nerves. The former are individual nerve cells; the latter are bundles of fibers.

The nerve fiber is essentially a protoplasmic extension (*axis cylinder*) from the body of the cell. This axis cylinder is sometimes clothed with a fatty *myelin* or *medullary sheath*. In some areas, a thinner nucleated membrane, the *neurilemma*, invests the axis cylinder, and if a myelin sheath is also present it lies between the neurilemma and the axis cylinder. Both of these coverings, when present, probably serve as insulation to prevent irradiation of impulses, and the neurilemma is an essential factor in the regeneration of nerve fibers.

Axons and dendrites may or may not have specialized *end organs*. Motor axons have *motor end plates* (Figure 24) that lie upon individual muscle fibers and are necessary for transmission of an impulse across the myoneural junction. Sensory fibers sometimes have specialized receptor end organs, such as the proprioceptor end organs discussed later in this chapter.

If a cell body is sufficiently damaged the entire neuron will degenerate irreversibly But if a process is severed or damaged, usually only the portion peripheral to the cell body will degenerate, and if the cell body and the neurilemma of the degenerated portion remain intact, the central end of the process may grow out (regenerate) along its former course by following the path provided by the neurilemma In the case of a cut nerve, the suturing to

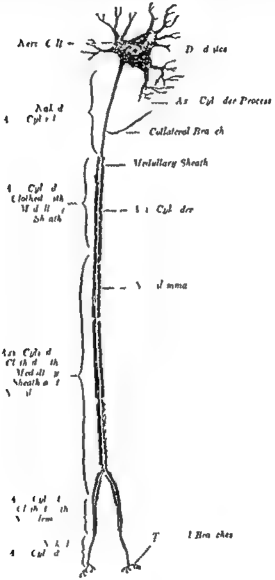


FIG 23 —A motor neuron (Stohr)

gether of the severed nerve ends may enhance the possibility of regeneration by approximately restoring the continuity of the neurilemma pathway Unfortunately no regeneration is possible if the cell bodies of motor nerves lying in the spinal cord are destroyed as is the case in poliomyelitis When a muscle atrophies both the muscle fibers and the motor endings diminish in size as is shown in Figures 25 and 26

Peripheral neurons (those extending outside the brain and spinal cord) may be divided into *afferent* or sensory neurons, and *efferent* or motor neurons Most nerves are *mixed nerves*—that is, they contain both afferent and efferent fibers Neurons within the spinal cord and brain are known as *internuncial* or *intercalated neurons* serving as connectors collators, integrators analyzers, and organizers of sensory and motor impulses

Neural Conduction A neuron is potentially capable of responding to electrical mechanical, chemical, or thermal stimuli although a receptor end organ may make it especially susceptible to a certain kind of stimulation In any event, an adequate stimulus causes a physico chemical change known as a *local excitatory state* (*l e s*) If the stimulus has sufficient strength duration and rate of change of intensity, the l e s triggers the propagation of a wave of excitation (nerve *impulse*) along the fiber—this is known as *conduction* The

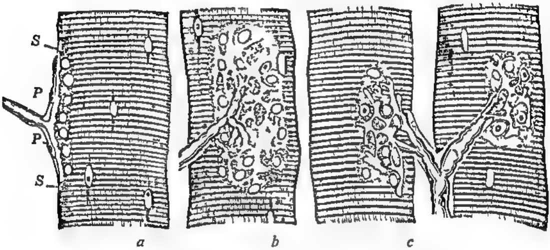


FIG 24 —Muscular fibers of *Lacerta viridis* with the termination of nerves *a* Seen in profile *P P* The nerve end plates *S S* The base of the plate consisting of a granular mass with nuclei *b* The same as seen in looking at a perfectly fresh fiber the nervous ends being probably still excitable (The forms of the variously divided plate can hardly be represented in a woodcut by sufficiently delicate and pale contours to reproduce correctly what is seen in nature) *c* The same as seen two hours after death from poisoning by curare (*Gray s Anatomy*)

nerve impulse is self propagating like a spark traveling along a string of gunpowder It is carried from the point of stimulation to all parts of the neuron at speeds up to 100 meters per second depending upon the diameter of the fiber and its physiological state at that moment A neuron obeys the all or none law—that is conduction depends on a stimulus whose intensity reaches a certain *threshold* value A stimulus of greater than threshold value has no extra effect on the quality of the impulse although it may irradiate at its point of application and cause conduction in adjacent neurons as well Muscle responses of varying magnitudes are not achieved by differences in the quality of the nerve impulse but as the result of (1) the number of neurons stimulated and (2) the frequency of impulses from repeated stimulation of neurons

After conduction there is an *absolute refractory period* (about 0 0004

FIG 25—Motor ending in gastrocnemius of normal male rat (× 450) (Cole)

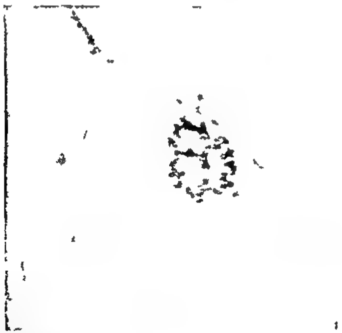


FIG 26—Motor ending in gastrocnemius of a male rat whose femur has been immobilized for twenty-eight days (× 450) (Cole)

second in mammals) during which no stimulus will arouse a response from the neuron This is followed by a *relative refractory period* (about 0 01 to 0 02 second) during which excitability gradually returns to normal and only an intense stimulus will arouse a response from the neuron

The Synapse The junction between two nerve fibers is called a synapse Here the ends of the axons are in very close contact with the brush like endings of the dendrites of other neurons Because each neuron is a discrete anatomical unit, the synapse becomes the point of communication between one neuron and another The nervous impulse travels along an axon and across the synapse to the dendrites of the other neuron, never in the reverse direction The synapse offers some resistance to the passage of the nervous impulse which may vary from one synapse to another It also causes a slight delay about 0 002 second in the transmission of the nervous impulse

The synapse acts as a one way valve or gate which permits the passage of the nervous impulse from one neuron to another Because of their variable resistance, synapses may tend to be selective and to direct the pathway of the nervous impulse nervous impulses resulting from feeble stimuli being conducted across only the synapses with low resistance but nervous impulses resulting from powerful stimuli crossing those with high resistance as well

ORGANIZATION OF THE NERVOUS SYSTEM

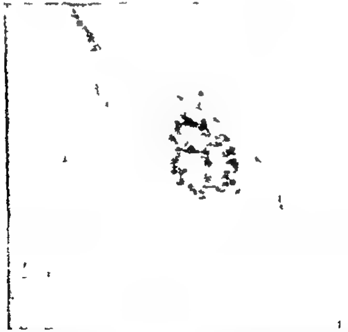
Divisions of the Nervous System The nervous system may be divided into (1) the *central nervous system* consisting of the brain and spinal cord, and (2) the *peripheral nervous system* consisting of all ganglia and nerves outside of the brain and spinal cord From another aspect the nervous system may be divided into the *autonomic* nervous system, which involves responses of the endocrine glands receiving a nervous supply, the heart, intestines, urogenital tract and blood vessels, and the *somatic* system which deals with sensory impulses and motor responses of the skeletal musculature

Cranial Nerves The peripheral nerves arising from the brain innervate skeletal muscles such as the muscles of the eyeball face and tongue but they are mainly concerned with olfaction vision taste balance audition and other sensory functions and with involuntary control of the heart lungs stomach and other viscera The spinal part of the *accessory nerve* (11th cranial nerve) is the only cranial nerve which innervates important postural muscles It arises by several roots from the cervical area of the spinal cord and is joined by branches of the spinal nerves from the cervical plexus before sending motor fibers to the sterno cleido mastoid and trapezius muscles

Spinal Nerves There are usually 31 pairs of spinal nerves arising from the spinal cord and leaving the vertebral canal through the intervertebral foramina Each of the 8 pairs of cervical nerves is named for the vertebra just below it (except the 8th which arises between the 7th cervical and the 1st thoracic vertebrae) and each of the 12 thoracic 5 lumbar 5 sacral and 1 coccygeal pairs is named for the vertebra just above it Spinal nerves are called *mixed nerves* because they are made up of both sensory and motor fibers along most of their length They are mixed in another sense too for most of them carry fibers of both the autonomic and somatic nervous systems

The Spinal Cord The spinal cord is a fluted column about 18 inches long and about one half inch in diameter although its diameter differs considerably at various levels Its features are best identified in cross section (Figures 27 and 28) At its center is the vertical *central canal* surrounded by an H shaped mass of gray (non medullated) matter The two dorsal extensions of the H are called *posterior horns* the ventral extensions are called *anterior horns*

FIG 25—Motor ending in gastrocnemius of normal male rat (X 450) (Cole)



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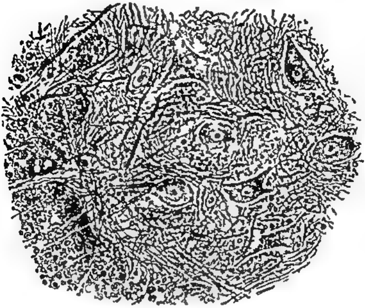

FIG 30 —Cross section of spinal cord on the border of gray and white portions (Klein)

been specifically named Their function is to connect different levels of the spinal cord with one another and with various higher centers of the brain

Microscopic study of the gray part of the cord shows it to consist mainly of cell bodies and non medullated nerve fibers of various sizes, having no uniformity of direction (Figure 30) Some of the fibers seen are the dendrites of

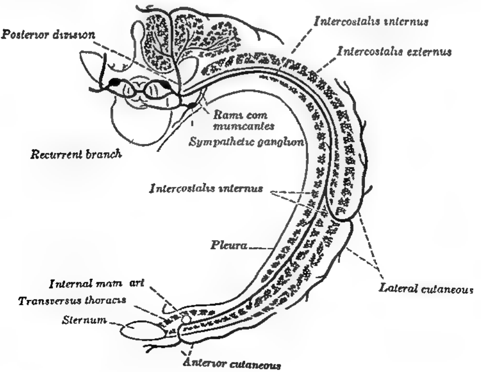

FIG 31 —Diagram of the course and branches of a typical intercostal nerve (Gray s Anatomy)

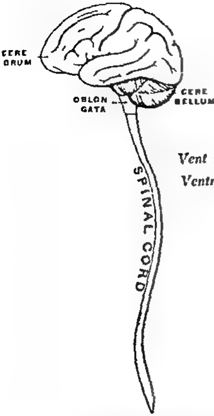

Fig. 27.—The central portion of the nervous system.

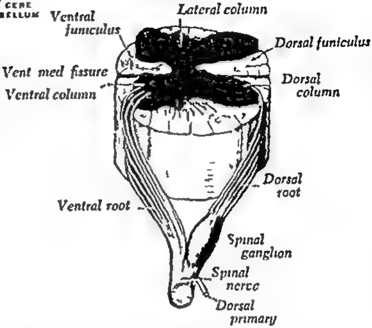

Fig. 28.—A spinal nerve with its anterior and posterior roots. (*Gray's Anatomy*.)

and the cross bar is called the *gray commissure*. Surrounding the gray matter is the medullated *white matter* of the cord, and this is marked off into right and left halves by a *posterior median septum* and by an *anterior median fissure*. The horns, gray commissure, septum, and fissure block off the white matter roughly into 6 parts, *anterior*, *lateral*, and *posterior* white columns on each side.

Microscopic study of the white columns shows them to be composed of medullated nerve fibers, the medullary sheaths being responsible for the white appearance. Most of these white fibers are arranged vertically, appearing in microscopic cross section as circles with dots in the center (Figure 29), a smaller number pass horizontally. The vertical fibers of the white columns have been functionally subdivided into numerous *tracts*, each of which has

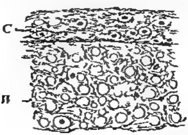

Fig. 29.—Cross section of a white column of the spinal cord. (Klein.)

the cell bodies, some are the axons of these cells, some are the terminals of axons from nerve cells situated in distant parts of the nervous system A large number of synapses occur in this area

Pathways of the Spinal Nerves The peripheral course of a typical spinal nerve is shown in Figure 31 As the spinal nerve root approaches the spine, it bifurcates into an afferent root carrying impulses of proprioception touch pain heat, cold, and so forth and an efferent root The former enters the spinal cord in the region of the posterior horn of the gray matter and is there fore termed the *dorsal* or *posterior* root, the latter enters the spinal cord in the region of the ventral horn of the gray matter and is termed the *ventral* or

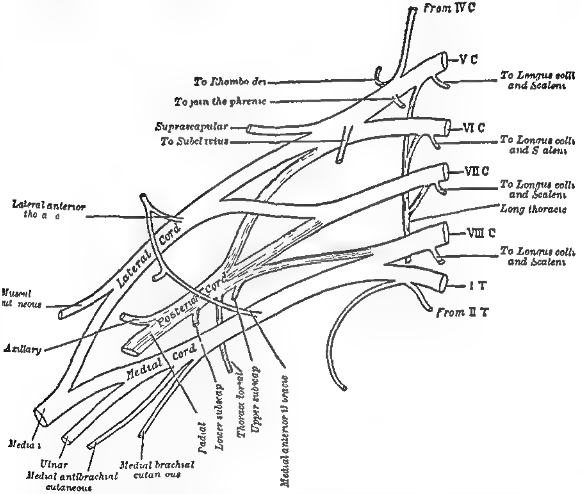

FIG 34 —Plan of brachial plexus (*Gray s Anatomy*)

anterior root (Figures 28 and 32) After entering the cord the afferent fibers take various courses some ending in the gray matter at the same level some taking a vertical course in the white columns and sending terminal endings into the gray matter at higher or lower levels and some traversing the white columns as far as the base of the brain They make synaptic contact in an exceptionally versatile manner either joining dendrites of motor neurons directly or joining dendrites of internuncial neurons The internuncial neurons serve as middlemen in transferring impulses to motor neurons at the same or different spinal levels or to higher centers in the brain

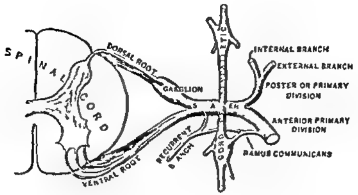

FIG 32 —Plan of the constitution of a spinal nerve (Keiller)

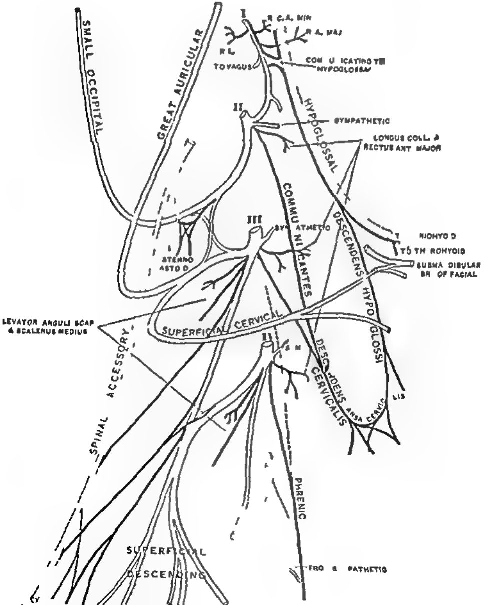

FIG 33 —Plan of cervical plexus

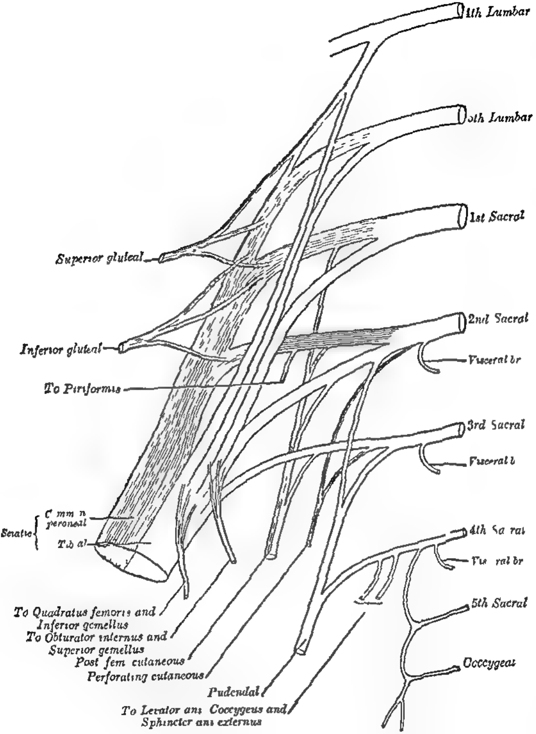

FIG 36 —Plan of sacral and coccygeal plexuses (*Gray's Anatomy*)

THE SIMPLE SPINAL REFLEX

A *reflex* is an involuntary muscle movement or glandular secretion resulting from some sensory stimulation Reflexes may be very complex and may involve the higher brain centers The simplest reflex is the *spinal reflex* which does not depend on any part of the brain (although a sensation of both the

The dendrites and cell bodies of efferent (motor) neurons are located in the gray matter of the spinal cord They collect impulses from fibers descending from the brain from internuncial neurons or directly from afferent spinal neurons of the same or different levels of the cord

The basic plan of distribution of spinal nerves is clearly an evolutionary holdover from that seen in limbless segmented lower forms At the cervical and upper thoracic spinal regions and in the lumbar and sacral spinal regions, the adjacent spinal nerves interconnect with each other in complex patterns These interconnections are called *plexi* of which there are five the cervical

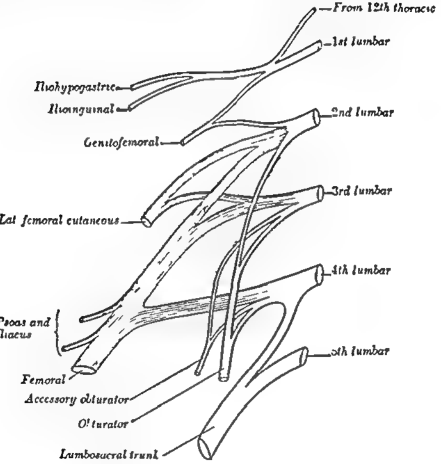

FIG 35 —Plan of lumbar plexus (*Gray s Anatomy*)

plexus (Figure 33) the brachial plexus (Figure 34) the lumbar plexus (Figure 35) the sacral plexus (Figure 36) and the coccygeal plexus (Figure 37) The details of arrangements of these plexi and of the resulting peripheral nerves are important to students of medicine corrective therapy physical therapy and occupational therapy who will need to refer extensively to detailed anatomy and neurology books in their studies of advanced kinesiology Physical educators generally require a less detailed knowledge of peripheral neurology but it is important for them to understand that athletic injuries may involve nerve trauma

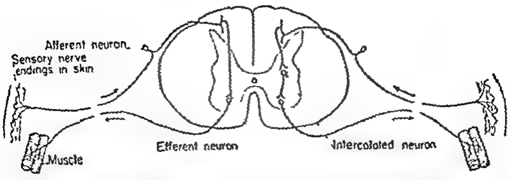

FIG 39 —Diagrammatic representation of simple spinal reflec arcs Arrows indicate direction of conduction (Kuntz *Neuro Anatomy*)

hand causes withdrawal of the limb, this could occur without awakening a sleeping person but the response is equally involuntary during wakefulness The sensation of pain reaches levels of consciousness after the fact, as it were and any further movements exclamations or other actions although perhaps reflective in nature could not be classified as either 'simple or 'spinal These additional by products of the simple reflex give some insight into the complexity and extent of neural connections since the original stimulus involved only a very few sensory neurons Such diagrams as Figure 39 indicate only the essential and basic elements of a simple spinal reflex a stimulus, a sensory ending a sensory neuron perhaps an internuncial neuron, a motor neuron and a muscle or gland

Corrective and physical therapists make use of some of the more complex reflexes in the treatment of certain types of patients Thus the spastic hand may be unlocked by placing it palm up over the buttocks of the prone patient and turning his head away from the involved side The evolutionary mechanisms underlying such phenomena and the ways in which reflexes of this type may be utilized have been summaried by Fay [1]

KINESTHESIA

Kinesthesia is the perception or consciousness of muscular movement and the position of one s body parts in space In part kinesthesia depends upon

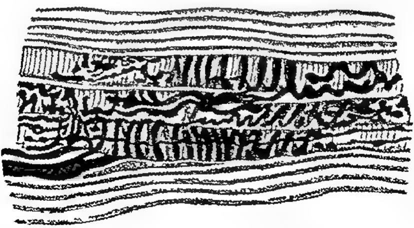

FIG 40 —Middle third of a terminal plaque in the muscle spindle of an adult cat (After Ruffini)

stimulus and the resulting motor action may be sent to the brain, even to the levels of consciousness as a by product of the workings of the reflex)

Anatomically, a minimum of two neurons is necessary for a spinal reflex A sensory neuron must carry the impulse resulting from the stimulus through the dorsal root pathway to the spinal cord In the cord the sensory neuron makes synaptic contact with a motor neuron which then carries the impulse through the ventral root pathway to a muscle or gland More frequently, a third neuron (an internuncial neuron) may mediate the impulse between the sensory and the motor neurons Perhaps several internuncial neurons may be involved

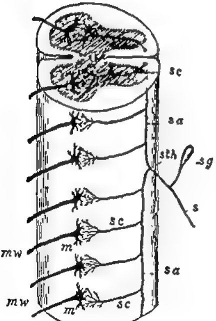

FIG 37 —A sensory neuron and its branches in the cord (Kolliker)

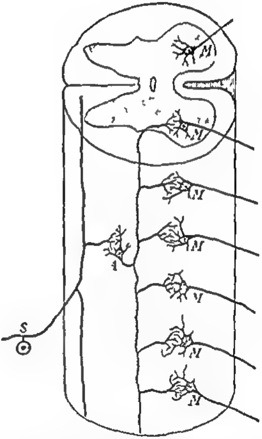

FIG 38 —An association neuron of the spinal cord *S*, sensory neuron, *A* association neuron *M M*, *M* motor neurons

Figures 37 and 38 make it clear that the motor activity resulting from a simple spinal reflex may take place at spinal levels other than the one through which the sensory neuron entered the cord Also the motor response may take place on the opposite side of the body The pathways shown in the figures have been kept to a minimum for simplicity the actual pathways might be much more complicated Further the diagrams assume that only one sensory neuron has been stimulated—an unlikely oversimplification of the probable situation in life

A great proportion of our actions are reflex in nature A pinprick on the

the *proprioceptors*, which receive sensations from the muscles, tendons, and joints and transmit them to the central nervous system

There are three main types of proprioceptive receptors the *muscle spindle*, the *Golgi tendon organ* and the *Pacinian corpuscle* The muscle spindle con

FIG 42 —Muriel Davis member of the 1956 United States Olympic Team and 1957 National A A U Women s all around gymnastics champion, holding a difficult version of the yogi stand Note that the position of the head makes it impossible to utilize visual clues to assist in maintaining the balance and the performers must depend almost entirely upon proprioceptive impulses from the hands for knowledge of the adjustments which must be made The ability to thus sacrifice certain input channels and still function perfectly is a sign of unusually fine kinesthetic proficiency

sists of a complicated structure of intrafusal muscle fibers innervated by sensory nerve endings These are enclosed in a capsule of connective tissue filled with lymph Some of the afferent fibers in these spindles are flat and wound in rings or spirals (annulo spiral endings) around the intrafusal fibers others lie on the surface of these fibers like a spray of flowers (flower spray

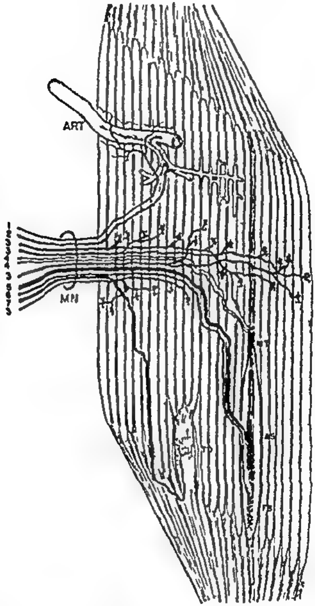

FIG 41 —Distribution of nerve fibers to a striated muscle The muscular nerve (MN) contains approximately 50 per cent of fibers derived from the anterior roots Of these the medium sized fibers (3,3 3) are distributed to motor end plates and the small fibers (4 4) to the end plates of muscle spindles Of fibers derived from the sensory nerve roots the largest (5 5 7) are distributed to muscle spindles (to the annulo spiral ending AS and the flower spray ending FS) and to tendon organs (TO) Small sensory fibers (1) often non medullated in their peripheral part are distributed in the connective tissue surrounding blood vessels Fibers derived from the sympathetic nervous system (2) are distributed to the muscular coats of arterioles and the smaller arteries (Adams Denny Brown and Pearson *Diseases of Muscle* courtesy of Paul B Hoeber Inc 1954)

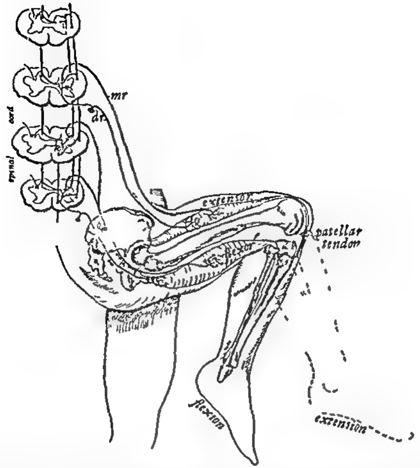

FIG 43 —Schema of the reciprocal innervation of the flexor and extensor muscles of the leg Cord has been rotated 90 degrees to the left (Papez *Comparative Neurology* courtesy of Thomas Y Crowell Company)

INHIBITION

It must not be supposed that because a reflex action *can* result from an adequate stimulus that it necessarily *must* result from such a stimulus The fact that it is possible for a person to hold still while receiving an intramuscular hypodermic injection shows that a withdrawal reflex is not always the result of pricking the skin Some combinations of nerve impulses result in inhibition of motor output In the somatic nervous system inhibition is always a function of synapses in the spinal cord and brain it does not occur peripherally or within a single neuron

Inhibition does not follow the all or none law a gradation or fluctuation in the degree of inhibition is possible [2] The reason is that inhibition raises the thresholds at the synapses, rather than blocking a nerve impulse directly or completely As thresholds rise fewer motor neurons respond to a stimulus of given strength Or as thresholds rise a stronger stimulus is required to make a given number of motor neurons respond The individual neurons still act under the all or none law

Examples of graded inhibition are seen in most voluntary movements

endings) The muscle spindles are stimulated by stretch of the muscle fibers whereas contraction tends to decrease their rate of discharge Golgi tendon organs are also composed of a bundle of fibers surrounded by lymph and enclosed in a fibrous capsule They are stimulated by either stretching or contracting Since the muscle spindles respond only to stretching the nervous system is able to distinguish between stretching and contraction according to whether both the spindles and Golgi organs are stimulated (stretching) or only the Golgi organs are stimulated (contraction) The anatomical arrangement of these organs is shown in Figure 40 and Figure 41

The Pacinian corpuscles are oval, laminated bodies somewhat like an onion in appearance They are organs of deep pressure sensitivity and are stimulated by deformation of the body tissues Some authors also consider free nerve endings as kinesthetic receptors, since these fibers accept the pain sensations and thus keep the nervous system informed of certain internal conditions Free nerve endings apparently do not penetrate the muscle fiber but seem to be numerous around tendons and joints

The kinesthetic receptors furnish the central nervous system with data regarding the position and movements of the limbs and other body parts This enables the nervous centers to produce the coordination of muscular tensions necessary for efficient movements In combination with the sensory organs they enable the body to make the changes in position necessary to maintain balance and to execute body movements Disturbances in the afferent motor impressions are one cause of the incoordinated movements known as ataxia

MYOTATIC OR STRETCH REFLEX

When muscles contract a stretch is exerted upon the tendons of their antagonists The proprioceptors in the stretched muscle set up a simple spinal reflex which causes the stretched muscle to contract Simultaneously, afferent impulses from the stretched muscle set up responses which inhibit the working muscles Passive movements such as gravity or some other external force may also initiate stretch reflexes

The best known and most studied stretch reflex is the *knee jerk* (Figure 43) When a person sits on the edge of a table with the lower leg hanging passively a tap on the patellar ligament about midway between the lower edge of the patella and the insertion of the ligament on the tibia stretches the quadriceps femoris muscle group There is an immediate reflex contraction of this muscle group causing extension at the knee joint

True stretch reflexes are a property of the antigravity muscles only In erect posture gravity tends to cause flexion at the neck spine hip knee and ankle joints In doing so it stretches the extensor tendons passing across the joints The myotatic contraction of these extensor muscles promptly corrects the tendency of the body to collapse The workings of the antigravity stretch reflex are clearly and amusingly seen in the bobbing nodding head of a person who goes to sleep while sitting in a chair During wakefulness such falling tendencies are much more finely controlled and erect balance is usually maintained smoothly The adjustments are ordinarily imperceptible but their total effect can be recorded with a sway meter which graphically indicates head movements during erect standing

the possible wisdom of starting a double play than with specific direction of his bodily actions

MOTOR LEARNING

It has been suggested that the properties of bone and muscle and the way in which they are constructed may account for many psychomotor abilities[4] However, the field of motor learning is so broad, so complicated, and so poorly understood that it would be absurd to attempt even an overview of principles within the scope of a text in kinesiology The following discussion, therefore, is fragmentary, and is limited to a few elementary applications of anatomic and kinesiological principles to the problem of learning to perform neuromuscular skills

Maturation and Motor Learning Maturation means growing accompanied by changes in functional ability, the emphasis is on 'ripening' rather than on changes in size shape, and volume Every teacher of motor skills should be familiar with the crucial relationship between physical or physiological maturation and motor learning For example, motor learning during the first two years of life is limited by the degree of myelination of nerve fibers, which is incomplete during this period Certain coordinations such as creeping and walking must await the development of myelin sheaths in the appropriate nerves and spinal tracts, perhaps to prevent a chaotic 'short circuiting' of the necessary impulses Because maturation is correlated highly with age, parents and teachers should become familiar with descriptions, such as those of Gesell and Ilg[5] of average abilities at various age levels so as to adjust teaching processes to the known periods of readiness of the child But because maturation is not perfectly correlated with age, an intelligent person should guard against a blind application of such norms Norms are guides and should never substitute for observation and testing of the individual child Girls for example mature faster than boys

Rathbone[6] has emphasized the progressive sequence in the development of motor skills dependent partly upon maturation Although a particular kind of skill cannot be mastered prior to the necessary physical maturation, attainment of the skill can be by passed perhaps irretrievably if the environment does not allow it to be mastered in the normal sequence, soon after maturation produces the potentiality Rathbone contends that crawling, for example is a vital activity in the development of trunk musculature, and that children who for some reason omit the crawling stage before learning to walk have missed a valuable neuromuscular experience which can never be replaced The relationship of such omissions to posture, visceral function, and physical development in later life needs to be investigated experimentally It is well known among physical education teachers that basic attainments in sports and aquatic skills are most easily achieved before or during adolescence, although the proportional influence of physical factors and social or psychological factors remains obscure

Perceptual Learning Many psychologists refer not to motor learning but to perceptuo motor learning, emphasizing the *unity* of perception and motor response Both reflexive and consciously directed motor activity are highly dependent upon cues and the *interpretation* of sensory stimulation Effective motor output may be inappropriate because of inability to perceive the mean-

The concept of co contraction (Chapter 4, pp 78–79) specifies that movement usually involves the simultaneous contraction of antagonistic muscle groups, although there may be a distinct difference in the forces exerted by the members of the pair When the external resistance to the agonists is great, the co contraction of the antagonists is minimal Apparently there is a central inhibitory effect upon the antagonists the purpose being to reduce the resistance to the movement This inhibition occurs as an involuntary though perhaps learned, reflex It is controlled in the spinal cord and lower levels of the brain, and is roughly proportional to the amount of force required in the agonists to perform the movement

A therapist, first aider, or athlete can sometimes make practical use of the phenomenon of inhibition of antagonists Muscle cramps and spasms, especially those of an acute nature, can sometimes be relieved by a strong voluntary or electrical stimulation of the muscle's antagonist

Like other reflexes the inhibition of antagonists may be over ridden or modified under certain conditions For example at the extreme range of motion the inhibited antagonist may be stretched, causing its myotatic contraction

Excessive general tension associated with emotional stress can also modify the reflex inhibition of antagonists In the early stages of motor learning such factors as fear, embarrassment and intense motivation can result in indiscriminate contractions of muscle groups thus interfering with smooth and effective performance Expert performers have learned coordinated patterns of contraction and inhibition These have been so strongly conditioned that only intense stresses are capable of interfering In any performer the removal of excess general tension minimizes the output of irrelevant motor impulses allowing the conditioned reflexes for contraction and inhibition to occur Coaches teachers and therapists who stress general relaxation, minimize fear, and use care in applying motivational stresses during the learning process are acting upon sound physiological and psychological principles

CONDITIONED REFLEXES

Although some reflexes are developed prenatally, most are learned It is a mistake to think of all reflexes as inherited reactions or as a limited number of very primitive reactions The usual goal in motor learning is to reduce the new movement patterns to subconscious automaticity dependent merely upon a push button sort of stimulus at either conscious or unconscious levels The nature of conditioned reflexes will be familiar to all readers who have had beginning courses in psychology [3] Highly complex motor activities such as those involved in sports situations may at first thought seem to be predominantly under conscious modification according to the changing environmental situation If the performer is an expert, this supposed emphasis on conscious direction may be false It is true that there must be attention to cues but the performance is likely to be a complex learned reflexive response The many re directions which occur during the performance are also reflexive arising directly in response to the stimuli of the changing situation rather than being deliberately and rationally inaugurated by the highest levels of the brain The conscious mind of a star shortstop while making a sensational pick up of a hard driven bounding ball is likely to be concerned more with

body which supercedes academic knowledge or analysis and a little trial-and-error learning frequently produces a more effective performance technique than could rigid direction

The seemingly authoritative descriptions of technique by champion athletes are sometimes at variance with the form they actually employ as shown by kinesiological and mechanical analyses using scientific methods Motion picture analysis and electromyographic studies have frequently uncovered discrepancies between what a performer thinks he does and what he really does The expert performer functions so largely on the reflex level that he does not find it necessary to analyze routine movements and is therefore often unconscious of precisely how he executes them For this reason experts are sometimes poor teachers whereas less accomplished individuals may be forced to develop the ability to analyze performance effectively

Practicing for Speed and Accuracy If a finished skill requires both high speed and great accuracy as does a tennis serve practice should emphasize both of the qualities from the beginning as much as possible If accuracy is emphasized to the neglect of speed much relearning must take place in the final stages of practice when a faster speed is employed A target-directed skill like pitching a baseball involves one kinesiological pattern when performed slowly and an entirely different pattern when performed rapidly The difference consists largely of variation in the degree of contraction of muscles antagonistic to the prime movers This difference between slow controlled movements rapid controlled movements and ballistic movements has been discussed in Chapter 3 pp 63–64

Speed of movement should not be confused with haste in performance In most gross skills speed infers the application of great force and the verbal admonition to the performer might well be harder or more forceful performance rather than faster performance General haste on the other hand is likely to cause a central irradiation of neural impulses to muscles whose contraction would be unnecessary or disadvantageous This is one reason why a performer ties up

Other Factors. It must be emphasized that the preceding discussion is selective covering only some implications which are derived from anatomical and kinesiological considerations Some of the most important topics in motor learning, such as specificity of motor learning the distribution of practice motivation and other topics have been omitted deliberately because they are outside the scope of this text

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ing of sensory input There may even be a basic sensory deficiency, therefore all learners should be screened for fundamental ability in sight and hearing and many teachers and coaches will wish to give additional or more discriminative tests before proceeding with instruction It may be anticipated that in years to come tests of kinesthesis will take their place beside those of vision and audition

Progression It is a matter of common observation that a child stands before he walks and walks before he runs Complex motor learning even more than other types of learning such as problem solving and rote memorizing requires an order of prerequisites a background of specific attainments Complex coordinations cannot be mastered until certain basic movement patterns have been reduced to the automaticity of conditioned reflexes [7] In general fine movements are distilled out of gross movements new skills are based upon recombinations of the elements of old skills It is a principle of physical education that early motor training should be broad, varied and general to provide a basis for later learning which is more refined specialized and complex This principle rests upon a sound neuromuscular basis

Relations Between Physical Abilities and Skills The learning of coordinated movement patterns is dependent upon the possession of sufficient amounts of fundamental physical abilities such as muscular strength flexibility muscular endurance and circulo-respiratory endurance This obvious relationship is sometimes ignored in mass instruction in physical education classes It is not unusual to see instructional classes in rope-climbing or gymnastics in which some pupils are too weak to support their body weight with their arm musculature! On the other hand the reverse of the principle also operates without a mastery of basic coordinations a youngster is unlikely to be able to participate in activities which will develop strength and endurance Effective physical education programs will be planned and conducted with this mutual relationship in mind

Individual Differences in Structure Structure influences performance The relationship may be either permissive or restrictive, and is variable according to the nature of each separate activity Each of the following factors, many of which are discussed extensively elsewhere in this text contributes to the individual differences which affect motor performance (1) Somatotype or body type (2) height of the body and length of bony levers (3) proportions of bone muscle and fat (4) specific gravity or buoyancy of the body (5) adequacy of nutrition (6) acuity of vision audition proprioception and other sensations (7) mobility of various joints (8) hereditary or congenital structural abnormalities and (9) residual defects from disease or trauma The trained kinesiologist views a performer or a would be performer with an analytic eye assessing his individual abilities and capabilities for particular activities

Standard Form Much kinesiology has implications for determining the mechanical technique or form to be employed by the learner Class teaching methods often imply that there is a best way to perform in a given situation whether it be postural adjustment crutch walking or participation in a sport But teachers should not insist upon too rigid a form In the first place better forms are still being discovered for most activities as the history of championship performance clearly demonstrates In the second place individual differences can never be completely understood There is a wisdom of the

produces rectilinear motion of the trunk forward and also rotatory motion of the trunk about a nearly vertical axis To all this is added the complex rotatory movements of the arm, utilizing the shoulder and elbow as centers of rotation, which results in the long curvilinear path described by the hand When released, the baseball may momentarily be in rectilinear motion and may undergo rotation as well In either case gravity immediately begins to pull it to earth causing it to follow a curvilinear path

When we study any particular muscular skill like throwing a baseball or some simpler example, we break it down into its parts identifying each portion as rectilinear rotatory or curvilinear motion or some combination of the three Each component then may be investigated further We must know the extent of each motion if it is short or long its direction its velocity the forces which cause it and where they are applied We might also wish to know whether the movement is powerful and capable of doing much work A knowledge of mechanics is necessary for such an analysis

Such terms as power, force and work are often misused and lead to unnecessary confusion and pointless speculation If we are to be successful in the application of any physical science we must agree on the meaning of the terms employed We must also understand and be consistent in the use of units and methods of measurement

There are two sorts of measurements which are used in problems dealing with mechanics

1 Scalar quantities which have magnitude only Examples are weight area and volume Scalar quantities of similar nature may be added arithmetically for example

$$\$10 + \$4 = \$14$$

2 Vector quantities which possess both magnitude and direction

Displacement velocity momentum acceleration and force are vector quantities

Vector Diagrams Vector quantities are often expressed diagrammatically by arrows The direction of the arrow represents the direction in which the quantity acts The length of the arrow drawn to some convenient scale represents the magnitude of the quantity For example we can diagram displacement in the following manner Suppose a man walks 4 miles north This can be represented by drawing a line 4 inches long in a direction representing due north

Addition of Vector Quantities Vector quantities unlike scalar, cannot always be added arithmetically It is obvious that, if after walking 4 miles due north the man turns and walks 3 miles east, his final displacement from the starting point is somewhat less than 4 plus 3 or 7 miles The final displacement can be found graphically by completing the vector diagram shown in Figure 44

After drawing the arrow OA representing a displacement of 4 miles north another line AB is drawn at a right angle representing a displacement of 3 miles east A third arrow R is drawn from O to B This is called the resultant and represents the magnitude and direction of the final displacement If R is measured carefully it is found to represent a displacement of 5 miles Using a protractor the direction is found to be 36 9° east of north

Chapter 6

Mechanical Principles

MOTION

MOVEMENTS of the human body are a result of the interaction of three separate forces Muscular contraction gravitational attraction, and external applications The study of such forces and the actions which they produce comprises the subject matter of *mechanics* when applied specifically to movements of living organisms it is often termed *biomechanics* Mechanics may be divided into *statics* dealing with objects which are in a state of equilibrium and *dynamics* which are concerned with objects in motion Dynamics in turn may be subdivided into *kinematics* which is the study of the motion of the body without regard to the forces acting on it and *kinetics* which treats with the forces which cause either motion or changes in motion

Motion may be of three general types

1 Rectilinear or translatory in a straight line
2 Angular or rotatory in a circular path
3 Curvilinear following a curved path

In the movements of our bodies in everyday life we find countless examples of all three types of motion In rectilinear motion every point on the object or body in motion moves the same distance in the same direction Rectilinear motion of the human body as a whole is demonstrated when we are seated in an automobile traveling on a straight highway The fist of the quickly extended left arm of the boxer usually follows a rectilinear path although other parts of the body moving at the same time do not necessarily undergo rectilinear motion

In angular or rotatory motion the body or body segment moves in an arc around some relatively fixed point which may or may not be a point within the body Rotatory motion is exemplified by a wheel turning about its axle In the human body it commonly occurs when a limb describes an arc as it swings from a joint When we walk or run the alternate rotatory action of our lower limbs utilizing the hip and knee as centers of rotation provides for the general rectilinear progression of the trunk and head

Rectilinear and rotatory motion may combine to produce curvilinear motion When throwing a baseball the rotatory action of the lower limbs

produces rectilinear motion of the trunk forward and also rotatory motion of the trunk about a nearly vertical axis To all this is added the complex rotatory movements of the arm, utilizing the shoulder and elbow as centers of rotation which results in the long curvilinear path described by the hand When released the baseball may momentarily be in rectilinear motion and may undergo rotation as well In either case gravity immediately begins to pull it to earth causing it to follow a curvilinear path

When we study any particular muscular skill like throwing a baseball or some simpler example we break it down into its parts identifying each portion as rectilinear rotatory or curvilinear motion or some combination of the three Each component then may be investigated further We must know the extent of each motion, if it is short or long its direction its velocity the forces which cause it and where they are applied We might also wish to know whether the movement is powerful and capable of doing much work A knowledge of mechanics is necessary for such an analysis

Such terms as power, force and work are often misused and lead to unnecessary confusion and pointless speculation If we are to be successful in the application of any physical science we must agree on the meaning of the terms employed We must also understand and be consistent in the use of units and methods of measurement

There are two sorts of measurements which are used in problems dealing with mechanics

1 SCALAR quantities which have magnitude only Examples are weight area and volume Scalar quantities of similar nature may be added arithmetically for example

$$\$10 + \$4 = \$14$$

2 VECTOR quantities which possess both magnitude and direction

Displacement velocity momentum acceleration and force are vector quantities

Vector Diagrams Vector quantities are often expressed diagrammatically by arrows The direction of the arrow represents the direction in which the quantity acts The length of the arrow drawn to some convenient scale represents the magnitude of the quantity For example we can diagram displacement in the following manner Suppose a man walks 4 miles north This can be represented by drawing a line 4 inches long in a direction representing due north

Addition of Vector Quantities Vector quantities unlike scalar, cannot always be added arithmetically It is obvious that if after walking 4 miles due north the man turns and walks 3 miles east, his final displacement from the starting point is somewhat less than 4 plus 3 or 7 miles The final displacement can be found graphically by completing the vector diagram shown in Figure 44

After drawing the arrow OA representing a displacement of 4 miles north, another line AB is drawn at a right angle representing a displacement of 3 miles east A third arrow R is drawn from O to B This is called the resultant and represents the magnitude and direction of the final displacement If R is measured carefully it is found to represent a displacement of 5 miles Using a protractor the direction is found to be 36 9 east of north

Chapter 6

Mechanical Principles

MOTION

MOVEMENTS of the human body are a result of the interaction of three separate forces Muscular contraction gravitational attraction and external applications The study of such forces and the actions which they produce comprises the subject matter of *mechanics* when applied specifically to movements of living organisms, it is often termed *biomechanics* Mechanics may be divided into *statics*, dealing with objects which are in a state of equilibrium and *dynamics* which are concerned with objects in motion Dynamics in turn may be subdivided into *kinematics* which is the study of the motion of the body without regard to the forces acting on it and *kinetics* which treats with the forces which cause either motion or changes in motion

Motion may be of three general types

1 Rectilinear or translatory in a straight line
2 Angular or rotatory in a circular path
3 Curvilinear following a curved path

In the movements of our bodies in everyday life we find countless examples of all three types of motion In rectilinear motion every point on the object or body in motion moves the same distance in the same direction Rectilinear motion of the human body as a whole is demonstrated when we are seated in an automobile traveling on a straight highway The fist of the quickly extended left arm of the boxer usually follows a rectilinear path although other parts of the body moving at the same time do not necessarily undergo rectilinear motion

In angular or rotatory motion the body or body segment moves in an arc around some relatively fixed point which may or may not be a point within the body Rotatory motion is exemplified by a wheel turning about its axle In the human body it commonly occurs when a limb describes an arc as it swings from a joint When we walk or run, the alternate rotatory action of our lower limbs utilizing the hip and knee as centers of rotation provides for the general rectilinear progression of the trunk and head

Rectilinear and rotatory motion may combine to produce curvilinear motion When throwing a baseball the rotatory action of the lower limbs

The resultants in vector diagrams may be found by trigonometric methods regardless of whether the vector diagram is a right or scalene triangle It is the method usually employed by the engineer The graphical method, in most cases, is the better suited to the needs of the kinesiologist Its accuracy depends upon the care and precision used in the construction of the scaled diagram

Vector quantities may be added arithmetically if the directions are the same If after walking 4 miles north a person walks an additional 3 miles north the final displacement is 7 miles If, however, after walking 4 miles north he returns south 3 miles, the final displacement is only 1 mile When two vector quantities are added the magnitude of the resultant may have a value lying anywhere between the sum and difference

Parallelogram of Forces Because of convenience the triangle method explained above is often replaced by the parallelogram method If we have two muscles exerting the two forces *OA* and *OB* applied at the point *O* we can draw the two vectors from this point From *A* we draw a line parallel

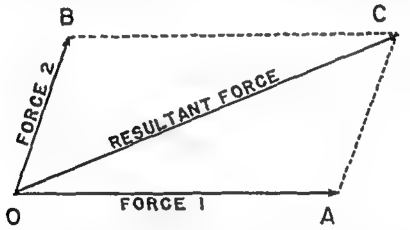


FIG 45 —Parallelogram of forces The addition of vector quantities

to *OB* and from *B* a line parallel to *OA* they will intersect at *C* The arrow OC represents the magnitude and direction of the resultant force of the combined efforts of the two muscles

If we have three forces *X* *Y* and *Z* acting on a point *O* we can find the resultant by first determining the resultant of *X* and *Y* This resultant then may be used as a single force and by a similar method we combine it with force Z which gives us the resultant of all three forces Any number of forces acting on a single point may be added by extending this method

Two or more muscles often pull on a common tendon of insertion The deltoid is in reality three separate muscles each of which exerts its force at a common insertion on the *humerus* Each however pulls at a quite different angle and the direction and magnitude of the combined pull depends upon the relative force exerted by each of the three parts The four extensors of the knee all attach to the upper border of the patella The combined force of their contraction is exerted at the tuberosity of the tibia through a single ligament which attaches the patella to the tibia Although each of the four muscles pulls at a different angle each contributes a component of force in the desired direction

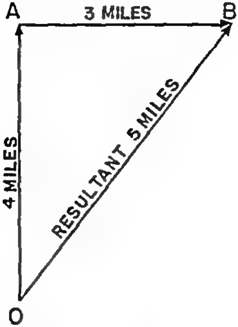


FIG 44 —The addition of vector quantities

This problem can also be solved by the use of the Pythagorean Theorem which states that the square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides

$$\overline{OB}^2 = \overline{OA}^2 + \overline{AB}^2$$

$$\overline{OB}^2 = 16 \quad + 9 = 25$$

$$OB = \sqrt{25} = 5 \text{ miles}$$

Five miles is the final displacement but we must also give thought to the direction

$$\text{Sine* of angle AOB} = \tfrac{3}{5} = 0.6$$
$$\text{AOB} = 36.9 \ \text{ east of north}$$

Muscles are usually attached to two bones with one or more intervening joints Muscular contraction provides a force which tends to draw the two attachments closer together This gives direction to the force and also indicates the point of application The magnitude of a force can be measured by its accomplishments The maximum force possible for a muscle to develop is in direct proportion to the cross sectional area of the muscle in a plane perpen dicular to the direction of the fibers Having both magnitude and direction muscular force can be represented by vector diagrams We have applied the concept of vector diagrams to displacement but it can be applied with equal success to any other vector quantity

* The sine of an acute angle of a right triangle is the ratio of the side opposite the angle to the hypotenuse The cosine is the ratio between the side adjacent to the angle and the hypotenuse

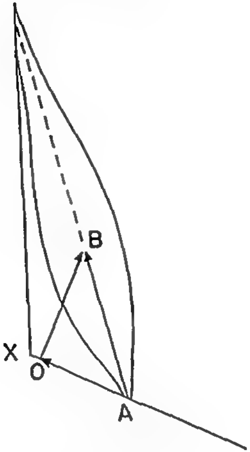


FIG 47 —Vectorial resolution of force

Trigonometrically

$$OB = AB \times \text{Sine } 60^\circ = 100 \times 0\ 866 = 86\ 6 \text{ lbs}$$
$$OA = AB \times \text{Cosine } 60 = 100 \times 0\ 5 = 50 \text{ lbs}$$

The graphical method can also be applied

KINEMATICS

Displacement In a case of pure rectilinear motion we measure displacement in feet miles meters or some other appropriate unit The direction may be expressed in terms of the points of the compass, its relation to vertical or horizontal planes or some other plane of reference

Velocity Velocity is the rate at which displacement occurs When we know the displacement of a moving object if we know the time which it takes to change position we know the average velocity with which it moved If for example a sprinter runs 100 yards in 10 seconds his average velocity is

$$\frac{100 \text{ yds}}{10 \text{ sec}} = 10 \text{ yards or } 30 \text{ feet per second}$$

$$\text{Average velocity is defined as } \frac{\text{distance traveled}}{\text{time}}$$

$$v = \frac{s}{t}$$

If we know the velocity and the elapsed time we can calculate the distance traveled

If a man walks at the rate of 3 5 miles per hour how far will he go in 3 hours?

$$s = t \times v$$
$$s = 3 \times 3\,5 = 10\,5 \text{ miles}$$

Time can also be calculated if we know the velocity and distance

$$t = \frac{s}{v}$$

If an athlete runs at a constant velocity of 20 feet per second how long will it take him to run 1 mile?

$$t = \frac{s}{v} = \frac{5280}{20} = 264 \text{ seconds} = 4 \text{ minutes } 24 \text{ seconds}$$

Speed Velocity is a vector quantity and has direction as well as magnitude Speed a term often confused with velocity is a *scalar* quantity and is concerned with magnitude alone Strictly speaking we should use the term velocity when motion is rectilinear or follows a circular path Speed is the appropriate term when motion is in an irregular or curved path If an automobile runs along a winding road at a constant speed of 20 miles per hour its velocity in any given direction is constantly changing due to the constant change of direction of the car

Acceleration Acceleration is the rate at which the velocity of a moving object changes A common example is when an automobile picks up speed If at one instant an automobile is moving at a velocity of 15 miles per hour but 10 seconds later its velocity has increased to 30 miles per hour, it has accelerated

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

In the previous example

$$\text{acceleration} = \frac{30 - 15}{10 \text{ sec}} = 1\,5 \text{ miles per hr per second}$$

which means that for each second the velocity of the car increases 1 5 miles per hour It is customary however to express such changes in understandable and consistent units In the above case

$$\text{acceleration} = \frac{44 \text{ ft /sec} - 22 \text{ ft /sec}}{10 \text{ sec}} = 2\,2 \text{ ft /sec /sec}$$

The automobile accelerates or its velocity increases 2 2 ft per second each second

Constant acceleration means that the change in velocity is uniform When the velocity of a moving object decreases acceleration is negative This slowing down is sometimes spoken of as deceleration Constant velocity is zero acceleration

Algebraically if $\text{acceleration} = \dfrac{\text{change in velocity}}{\text{time}}$

Change in velocity = acceleration × time
$$v - v_0 = at$$

Without considering its derivation the following equation expresses displacement after a given time with constant acceleration

$$s = v_0t + \tfrac{1}{2}at^2$$
$s = \tfrac{1}{2}at^2$ provided the initial velocity is zero

Acceleration Due to Gravity Gravity supplies a special case of constant acceleration It varies about one half of one per cent over the earth's surface Its legal value is 32 17 ft /sec /sec For convenience in solving problems the value is commonly assumed to be 32 ft /sec /sec or 980 cm /sec /sec Gravity is important to the anatomist and kinesiologist and is an important feature of our environment All terrestrial animals, in contrast to aquatic life upon which the effect of gravity is relatively negligible, have during the course of their evolution arranged their skeletal structure and the internal design of their bones in a manner calculated to best support the body against the pull of gravity One of the major duties of our muscles is to maintain our erect posture against gravity which constantly tries to pull us to earth In order to exercise this function efficiently the attachments of our muscles, their relative dimensions and chemical composition have in the course of evolution adapted themselves to the requirements of their arduous task Because it represents a constant downward force, gravity must always be reckoned with when we analyze muscular movement

The laws of acceleration in general apply to the special case of gravity In the formulae used the symbol *g* is ordinarily substituted for *a*

$$g = \frac{v - v_0}{t}$$
$$v - v_0 = gt$$
$$s = \tfrac{1}{2}gt^2$$

Kinematics—Rotatory Motion The same concepts of rectilinear motion apply to angular or rotatory motion except that displacement is measured in revolutions or the angle turned through The latter is usually expressed in degrees or in scientific work as radians A radian is 57 3° and is the angle subtended by an arc on a circle equal in length to the radius of the circle

2π radians = one revolution or 360

ANGULAR VELOCITY is commonly expressed as revolutions or radians per minute or per second

$$\omega = \frac{\theta}{t}$$
ω = angular velocity
θ = angle in radians
t = time

ANGULAR ACCELERATION like linear acceleration is the rate of change of angular velocity

$$\alpha = \frac{\omega - \omega_0}{t}$$

KINETICS

Sir Isaac Newton was first to arrive at an understanding of kinetics and as a result formulated three laws of motion which express the fundamental principles of dynamics

1 A body remains in a state of rest or of uniform motion unless acted upon by some external force

2 When a body is acted upon by a single external force its resulting acceleration in the direction of the force is proportional to the force and inversely proportional to the mass of the body

3 To every action force there is an equal and opposite reaction force

In the study of the causes of motion it is necessary to introduce two new factors mass which is related to weight and force Neither mass nor force are necessary for the study of kinematics It is difficult to visualize just what is meant by mass and how it differs from weight An object has mass wherever its location, as for example, in interstellar space but when it is acted upon by gravity we are able to measure the force it exerts toward the earth s center which is its weight

When we employ any of the equations of dynamics which incorporate the mass of an object if we know its weight we must to be consistent convert the numerical value of the weight into that of mass The mathematical relationship is such that if we divide the weight of an object in pounds by 32 ft / sec /sec the acceleration due to gravity we obtain the correct numerical value for its mass

$$m = \frac{W}{g}$$

Newton's First Law of Motion Applications of Newton s First Law are easily observable in our everyday life We are all familiar with the difficulty encountered when trying to move anything very heavy and likewise we know the difficulty experienced when attempting to stop a heavy moving object This law is often called the Law of Inertia and is really a statement of this property Not only are we concerned with the force needed in moving a body or limb but antagonistic muscle groups are often called upon to retard motion of a limb or body once motion has been initiated

A familiar experiment used to demonstrate inertia is done by placing a new playing card on an inverted drinking glass A coin is placed on the card The card can be jerked out quickly leaving the coin in place Because of its inertia the coin which was at rest remained at rest despite the movement of the card Similarly it is this tendency of a moving body to maintain its course which makes it difficult for an athlete to change his direction while running at top speed

Newton s laws of motion are valid under the idealistic conditions imposed for their derivation Friction is considered to be non existent whether it be between the moving body and the surface over which it travels or between the moving body and the air From the statement of the First Law we would conclude that once an object has been set in motion it would continue to move with a constant velocity without the application of additional force This we know not to be the case in a concrete situation External resistance resulting from friction and wind resistance must be overcome otherwise the moving body will come to rest It is therefore necessary to apply additional

force to keep the body in motion and also necessary to introduce such factors as ground and wind resistance into the calculation of many problems of kinesiological kinetics, especially when the body moves at high speed, as in sprinting or throwing They are properly regarded as forces operating to prevent or retard movement of the body or object and therefore must be overcome The consideration of such additional factors increases the complexity of problems of kinetics but in no way affects the validity of Newton's Laws

In the study of kinesiology we seldom if ever have a case where only one component of force is considered In our problems we usually deal with resultant forces These resultant forces are of course subject to analysis by the parallelogram of forces' technique which may require one or more steps depending upon the number of primary forces involved Gravity is nearly always a force with which we must reckon This is true with even a simple movements of a limb and becomes of great importance in the study of complex coordinations such as the throwing of a baseball

Momentum Momentum is defined as the product of the mass of an object times its velocity and expresses the force with which a moving body strikes another as well as the force originally required to give it motion

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

Because all moving bodies have momentum it is an important factor in kinesiology and in sports participation body contact sports in particular A small fast charging linesman in football may compensate for his light weight by moving faster than his more bulky opponent

Conservation of Momentum When one moving body strikes another, momentum is not lost but is conserved If a large heavy ball is rolled and strikes a smaller stationary one if the collision is elastic it slows down and loses momentum but the loss of momentum of the larger ball is exactly balanced by the gain in momentum of the smaller one In a head on collision between two objects of equal weight and velocity (equal momentum) moving in opposite directions they will both come to a stop Here momentum is again conserved because each had the same momentum but in opposite directions

Newton's Second Law of Motion From the statement of the Second Law we can set up the following equation representing the relationship between force mass and acceleration

$$\text{Force} = \text{mass} \times \text{acceleration}$$
$$F = ma$$

If weight is used we can substitute

$$m = \frac{W}{g}$$
$$F = \frac{W}{g}a$$

We also know that acceleration is change in velocity therefore we may also substitute the difference in velocity for acceleration

$$a = \frac{v - v_0}{t}$$
$$\text{Force} = \frac{m(v - v_0)}{t} = \frac{mv - mv_0}{t}$$
$$mv - mv_0 = \text{change in momentum}$$

Force then becomes the change in momentum of a moving object in unit time. Newton's original statement of his Second Law was in terms of the change in momentum. *The rate at which the momentum of a body changes is equal to the force acting and takes place in the direction of the straight line in which the force acts.*

Consideration of the change of momentum of any object for a given time interval gives us the Force Impulse equation

$$Ft = mv - mv_0$$

The relationship expressed is useful in the solution of problems where force is applied to an object for a known period of time and produces a change in momentum of the object. Typical situations are those where sprinters or jumpers take off, where balls are struck with various sports implements such as bats, racquets, and golf clubs, or in engineering where a hammer of any type is used.

Example. A standard 1.6 oz. golf ball is struck with a club and given a velocity of 150 feet per second. If we know that the club head is in contact with the ball for .005 second, by using the Force Impulse equation we are able to calculate the required force in pounds weight.

$$Ft = \frac{W}{g}v - \frac{W}{g}v_0$$

$$F = \frac{\frac{W}{g}v - \frac{W}{g}v_0}{t}$$

The second term in the numerator disappears because the ball starts from rest and its initial velocity is zero.

Converting ounces to pounds

$$F = \frac{\frac{0.1}{32} \times 150}{0.005} = 93.75 \text{ lb weight}$$

It is also possible to calculate the distance the club head is in contact with the ball.

$$\frac{v - v_0}{2} = \frac{150 - 0}{2} = 75 \text{ ft. per sec. average velocity}$$

$$75 \times .005 = .375 \text{ feet}$$

When we know the results of our physical efforts in terms of change of momentum of objects thrown or struck, we are able to calculate the minimum force which contraction of our muscles must produce to cause such changes. The experimental determination of the values of trunk, limb and missile accelerations would make it possible to explore the kinetics of complicated movements such as throwing a ball, discus or javelin or swinging a bat, racquet or golf club. Here is a whole field of kinesiology, little explored as yet, which in the future may yield much information concerning the performance of the human body.

Newton's Third Law of Motion. The application of the principle of equality of action and reaction is well understood by almost any athlete or workman

The concept that forces always occur in couples with each vector equal in magnitude, but opposite in direction, explains the firm footing needed and the drive by the legs when a ball is thrown, a blow is struck or for walking or running An excellent example of the Third Law is the "kick or recoil experienced by the soldier or hunter when firing a gun The force exerted on the gun is equal but opposite in direction, to the force exerted on the projectile The far greater weight of the firearm necessarily causes it to have a relatively small acceleration as compared to that of the projectile which weighs very little

In all actions where the human body is propelled forward or employed to hurl or strike objects an appreciation of the Third Law and all of its implications is of great importance in efficient and effective performance

KINETICS OF ROTATORY MOTION

When we consider the kinetics of rotatory motion, as with rectilinear motion we find it necessary to introduce two new factors In place of mass we apply the concept of moment of inertia and we speak of the torque exerted instead of force

Moment of Inertia The moment of inertia J of an object with respect to the axis about which it rotates is equal to the mass of the object times the square of its distance from the center of rotation This relationship holds for small objects which are distant from the center of rotation, as for example, when we tie a string to a rock and swing it round and round In kinesiological problems involving rotatory motion we are usually confronted with a different situation Portions of the body such as a limb rotating around a joint have unusual and non uniform distributions of their mass The moment of inertia of such irregularly shaped bodies is calculated by getting the sum of the moments of inertia of all the various subdivisions Physics textbooks usually list the formulae used in calculating the moment of inertia of objects of various shapes We may find it necessary to consider the moment of inertia of the trunk of the body A justifiable and simple approximation is to consider the trunk to be a solid cylinder the moment of inertia of which, when it revolves about a central axis, is $\frac{1}{2}mr^2$ When we consider a tapering limb such as the thigh it becomes necessary to consider it as the frustrum of a cone If it is rotating about its central axis, the moment of inertia,

$$J = \frac{3}{10} m \frac{(R^5 - r^5)}{(R^3 - r^3)}$$

If we are considering a limb with a nearly uniform cross section and the axis of rotation at one end like an arm being swung from the shoulder with the elbow extended the moment of inertia

$$J = \frac{1}{3}ml^2$$

where l is the length of the arm Each problem in biokinetics involving rotatory motion requires that certain arbitrary assumptions be made in order to evaluate the moment of inertia The accuracy of the final solution in a great measure depends upon the validity of the assumptions

Torque When a force tends to cause an object to rotate it exerts torque Torque is equal to the product of the force times the perpendicular distance

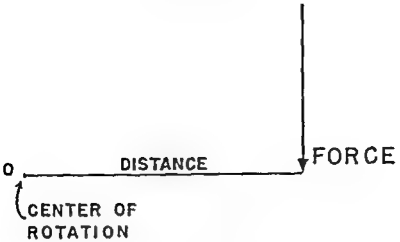


Fig 48 —Torque

from point of application of the force to the axis of rotation. Torque is also called Force Moment.

$$\text{Torque} = \text{Force} \times \text{radius}$$
$$T = Fr$$

Angular Momentum Angular momentum is similar to rectilinear momentum, being the product of the moment of inertia times the angular velocity.

$$\text{Angular momentum} = J\omega$$

Conservation of Angular Momentum Momentum is conserved in rotatory motion as it is in rectilinear motion. Many sports utilize this principle to produce certain effects. The figure skater in order to pirouette or whirl at a high angular velocity will bring her angular velocity to a maximum with her arms outstretched. Once the velocity reaches its peak the arms are brought in as close to the axis of rotation as possible. Because the angular momentum does not immediately diminish, the angular velocity will necessarily increase because of the decreased radius since the mass remains the same.

When the skater wishes to slow down preparatory to stopping the pirouette the arms are again outstretched and possibly a leg abducted. In accordance with the principle of conservation of momentum, the angular velocity will be reduced.

If we have a weight attached to a string and swing it in a circle keeping the momentum constant, if we shorten the string by 50 per cent we double the tangential velocity of the weight. Because the radius of the circle is 50 per cent smaller, the angular velocity increases to four times its original value. This relationship explains the apparent sudden increase and decrease of speed of rotation by the skater in the pirouette.

Rotational Force-Impulse Equation This is analagous to the Force Impulse equation of rectilinear motion and can be applied to the solution of problems of the same type but which involve rotatory motion.

$$Ft = J\omega - J\omega_0$$

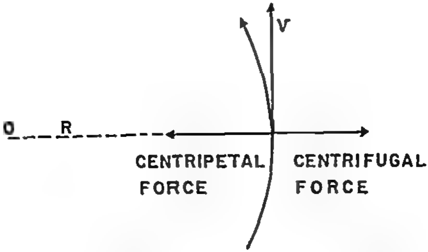


FIG 49 —Centripetal force neutralized by an equal and opposite centrifugal force

Centripetal and Centrifugal Force When we swing a weight on a string in a circle or hold a discus in our hand and whirl around preparatory to throwing we find it necessary to pull inward on the string or discus to prevent the weight from flying outward The faster the speed of rotation the greater the force required to hold it This inward force is called the centripetal force In accordance with Newton s Third Law there is an equal and opposite outward force exerted by the missile which is known as the centrifugal force

If we release the weight or discus it flies off tangentially as indicated by the arrow v Centripetal force acts to pull the weight toward the center At any instant when it fails to act the weight will fly off in a straight line tangential to its circular path This can be predicted from Newton s First Law We are all familiar with the fact that mud is thrown tangentially from an automobile tire when the centrifugal force caused by increased angular velocity (speed) overcomes the adhesive properties of the mud

Centripetal force is an important fact in all violent movements of our limbs If we swing an arm violently like the weight on the string or discus it tends to detach itself from the shoulder and fly away tangentially This is prevented by the holding action of the ligaments and by the centripetal force exerted by the muscles spanning the joint

Both centrifugal and centripetal forces are expressed by the formula

$$F = \frac{WV^2}{gr}$$

where

W = weight of the object
V = velocity in feet per second
g = force of gravity (32 ft /sec)
r = radius of the circle

WORK

When we consider muscular movement in man we are usually interested in whether or not work can be accomplished This holds true for sports as

well as for industrial occupations Work is defined as the product of the force times the distance through which it acts

$$W = F \times S$$

If we lift a 10 pound weight a distance of 5 feet we have accomplished $10 \times 5 = 50$ foot pounds of work If the weight is 100 pounds and the distance the same, the work is ten times greater The work is done against the force of gravity If we endeavor to lift a weight of 1000 lbs and find it quite beyond our ability in spite of the fact that we may make a strong effort, in the end the weight remains in place and we have done no work

If we slide a 10 pound weight along a horizontal surface with a force of 2 pounds, if we move the weight a distance of 5 feet the work done is 2×5 or 10 foot pounds In this case work is done against friction which acts as an opposing force

POWER

Power is often confused with work Power is the rate at which work is done The shorter the time that it takes to accomplish a given amount of work the greater the power required

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

The most commonly used unit of power is that of horsepower which is 550 foot pounds per second

If a weight lifter requires 2 seconds to lift a 100 pound weight to the height of 6 feet he has done 100×6 or 600 foot pounds of work, but has required 2 seconds Since power is the rate of doing work in one second he has done on the average

$$\frac{600}{2} = 300 \text{ foot pounds of work each second or at the rate of}$$

$$\frac{300}{550} \text{ or } 0\ 545 \text{ HP}$$

CURVILINEAR MOTION

Because curvilinear motion is a combination of rectilinear and rotatory motion and the possibilities are infinite it is beyond the scope of this text to adequately treat this complex subject Aside from the movements of the body perhaps the most common case of curvilinear motion encountered by those who study muscular movement center around the path of missiles such as the baseball shot javelin and discus Were it not for air resistance paths of these objects would be that of a parabola from the point of release to its return to the same horizontal level This much of the missile s flight can be calculated by the formula

$$R = \frac{V^2 \sin \theta}{g}$$

but an additional and more complicated formula must be used to compute the R from the time of its return to the horizontal plane until it strikes the ground (Fig 50) In heavy slow moving objects like the 16 pound shot air resistance

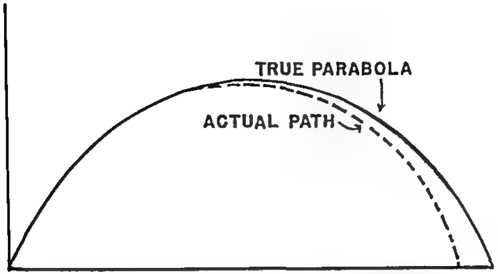


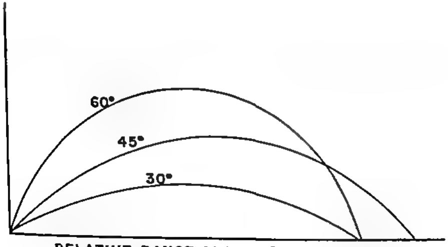
FIG 50.—Actual path of a missile compared to a true parabola

is negligible and can be disregarded When the missile moves with a relatively high velocity like a rifle bullet or even a baseball, the matter of air resistance assumes increasing importance with increasing velocity Air resistance varies with the square of the velocity If the speed is doubled the resistance becomes four times greater This reduces the velocity and distance traveled, and, as a result, the paths described by missiles of high velocity are not true parabolas

Disregarding air resistance when an object is thrown, the maximum range is expressed by the formula

$$\text{Range} = \frac{v^2}{g} \text{Sine } 2\theta$$

Because Sine 2 θ reaches its maximum of one when $\theta = 45°$, extreme range is reached when the angle of departure of the missile is at an angle of 45° (Fig 51)



RELATIVE RANGE AND HEIGHT REACHED AT DIFFERENT ANGLES OF ELEVATION
FIG 51

well as for industrial occupations Work is defined as the product of the force times the distance through which it acts

$$W = F \times S$$

If we lift a 10 pound weight a distance of 5 feet we have accomplished $10 \times 5 = 50$ foot pounds of work If the weight is 100 pounds and the distance the same, the work is ten times greater The work is done against the force of gravity If we endeavor to lift a weight of 1000 lbs and find it quite beyond our ability, in spite of the fact that we may make a strong effort, in the end the weight remains in place and we have done no work

If we slide a 10 pound weight along a horizontal surface with a force of 2 pounds if we move the weight a distance of 5 feet the work done is 2×5 or 10 foot pounds In this case work is done against friction which acts as *an opposing force*

POWER

Power is often confused with work Power is the rate at which work is done The shorter the time that it takes to accomplish a given amount of work the greater the power required

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

The most commonly used unit of power is that of horsepower which is 550 foot pounds per second

If a weight lifter requires 2 seconds to lift a 100 pound weight to the height of 6 feet, he has done 100×6 or 600 foot pounds of work, but has required 2 seconds Since power is the rate of doing work in one second he has done on the average

$$\frac{600}{2} = 300 \text{ foot pounds of work each second or at the rate of}$$

$$\frac{300}{550} \text{ or } 0\ 545 \text{ HP}$$

CURVILINEAR MOTION

Because curvilinear motion is a combination of rectilinear and rotatory motion and the possibilities are infinite it is beyond the scope of this text to adequately treat this complex subject Aside from the movements of the body perhaps the most common case of curvilinear motion encountered by those who study muscular movement center around the path of missiles such as the baseball shot javelin and discus Were it not for air resistance paths of these objects would be that of a parabola from the point of release to its return to the same horizontal level This much of the missile s flight can be calculated by the formula

$$R = \frac{V^2 \sin \theta}{g}$$

but an additional and more complicated formula must be used to compute the R from the time of its return to the horizontal plane until it strikes the ground (Fig 50) In heavy slow moving objects like the 16 pound shot air resistance

Chapter 7

Simple Machines

THE force of muscular contraction must be effectively harnessed if we are to utilize it to perform useful work The body is able to do this by utilizing mechanical principles to operate certain simple machines inherent in its design The machine most often used is the lever

LEVER ACTION

A lever is a rigid bar revolving about a fixed point called the axis or fulcrum The usual function of a lever is to gain mechanical advantage whereby a small force exerted through a great distance can be converted into a greater force operating through a lesser distance Mechanical advantage in the case of a lever is the ratio of the length of the force arm to that of the resistance arm In most machines this application is the rule however, in the human body this relationship except in a few cases, is reversed and we find distance and speed of movement gained with an associated loss of mechanical advantage The principle of the lever is a simple mechanical feature found in nearly all machines The human body as a machine is not an exception, consequently most of the movements accomplished by the body employ this principle At times the nature of the application of leverage is not immediately apparent and numerous controversies have arisen in kinesiological circles Confusion arises from attempts to classify the lever action of the movement of certain joints A precise interpretation of the definition of lever action can be depended upon to clarify such questions

In making bodily movements aside from lending support it is the principal function of the bones to serve as levers with the muscles supplying the force which moves them The joints of course serve as fulcra It is only by such action that the body is able to assume the erect position walk, run jump swim or to move in any way as well as to manipulate other objects

A lever such as one of the bones of the arm may have various degrees of usefulness for a given purpose, depending upon the location of three points upon it the point where the force is applied to it the point where the resistance we wish to overcome is applied and the fulcrum or axis about which it

Maximum height is found by the following relationship

$$\text{Height} = \frac{(v \text{ Sine } \theta)^2}{2g}$$

When Sine θ reaches a maximum of one or $\theta = 90°$ the maximum height will be reached

The time the missile is in the air is expressed as follows

$$T = \frac{2v \text{ Sine } \theta}{g}$$

PROBLEMS

1 A cross-country runner travels due north for one half hour moving at the rate of 10 miles per hour he then turns and runs northeast at the same rate for 45 minutes Using the graphical method find his final distance and direction from the place he started

2 How long will it take a runner to go 2 miles if he averages 18 feet per second?

3 If a runner covers one mile in 4 minutes 8 seconds what is his average velocity in feet per second?

4 A sprinter running 100 yards reaches his maximum velocity of 30 feet per second at the 10 yard mark He maintains this velocity to the finish If it takes him 10 5 seconds to run the total distance what is his average velocity for the first 10 yards?

5 A weight tied to a string is swinging round and round at the rate of seven revolutions in two seconds What is its angular velocity in revolutions per minute? In radians per second?

6 What is the momentum of a 150 pound sprinter moving at the rate of 30 feet per second?

7 How much work is required to lift a 150 pound weight through a distance of 3 feet? How much work is done if the weight is lowered through the same distance?

8 How much horsepower is required if we lift one ton through a distance of 20 feet in 5 seconds?

9 What horsepower must a 180 pound man develop to carry a 100 pound sack of grain to a height of 50 feet in two minutes?

10 A projectile is fired from a gun at a velocity of 2200 feet per second Disregarding air resistance calculate the range if the angle of departure is 30 45 and 60 What height would the projectile reach if the gun was pointed vertically?

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2 *Correlation of Basic Sciences with Kinesiology* New York American Physical Therapy Association April 1955

3 Efron Alexander *Mechanics* New York John F Rider Publisher Inc 1958

4 *Sir Isaac Newton s Mathematical Principles of Natural Philosophy and His System of the World* July 5 1668 English translation by Andrew Motte 1729 revision by Florian Cajori Berkeley University of California Press 1948

to the axis and the force much farther away since the lever is used to gain force at the expense of distance of movement In the body, as illustrated by the two muscles in Figure 53, the force is usually applied with a short muscle arm to overcome a resistance much farther away the penniform arrangement of muscle fibers gives a large amount of force and the leverage is such as to give great distance of movement and speed This plan of construction not only gives the body all the power, speed, and extent of movement that is needed but also compactness of structure the muscles lying much closer to the bones than would be possible with longer force arms

First Class Lever Levers of the first class have the fulcrum located between the point where the force is applied and the point where the resistance is encountered As a consequence the force and the resistance act in the same

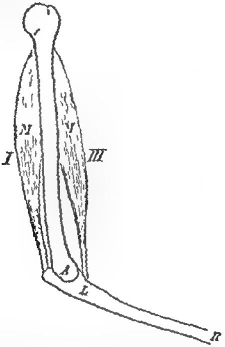

FIG 53 —Illustration of first class and third class levers by muscles acting on the elbow joint The bone *AR* is the lever with the axis at *A* the weight or resistance at the hand which is beyond *R* *M* *M* are the muscles and *L* is the insertion of the muscle *III*

direction and the two arms of the lever move in opposite directions This type of lever is illustrated by a crow bar a pair of scissors a simple teeter or in the case of the human arm by the action of the triceps when it extends the arm Note the action of Muscle *I* in Figure 53 In this case the elbow joint (*A*) acts as the fulcrum This is a typical case where power is sacrificed in order to obtain greater range and speed of movement

If when seated at a table the right hand is placed palm downward on the table top with the elbow at the side and flexed at an angle of 90° a force of ten pounds is applied to the table top what is the force of contraction of the triceps? Assume the force to be applied by the palm 12 inches from the ful crum which is the elbow joint The triceps is attached to the ulna on the opposite side of the fulcrum and one inch from it

turns Accordingly, levers are divided into three classes depending upon the relative positions of these three points as illustrated in Figure 52

Law of Levers The distance from the fulcrum to the point where force is applied is called the force arm or power arm of the lever The distance from the fulcrum to the point where resistance is applied is called the resist ance arm or weight arm In Figure 53 *AL* is the power arm and *AR* is the resistance arm for muscle *III* The law of levers which applies to all three classes alike, states that the force will exactly balance the resistance when the product of the force times the length of the force arm is equal to the product *of the resistance times the length of the resistance arm*

Force × Force Arm = Resistance × Resistance Arm

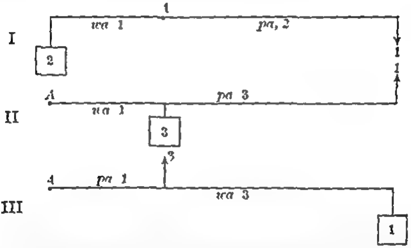

FIG 52—The three classes of levers The long straight lines are the levers *A* is the axis the squares represent the weight or resistance and the arrows the power or pull of muscle *pa* power arm *wa* weight arm

Because we are in reality considering a case of rotatory motion when we consider a force applied on a lever at a distance from the center of rotation (fulcrum) we can say that balance is achieved when the torques exerted on each arm of the lever are equal This statement of the law of the lever neglects the weight of the two arms of the lever itself which in a concrete situation is always a significant factor and must be considered

When a lever turns about its axis it is evident that all points upon it move in arcs of a circle and that the distances these points move is proportional to their distances from the axis In the case of muscle *III* for example if the weight is six times as far from the axis as the muscle it will move six times as far, so that when the muscle contracts through one inch the weight will be lifted through 6 inches The relation of this fact to the law of levers given above is stated in the law of conservation of energy which says that in the use of levers all that is lost in force is gained in distance and *vice versa* Since the time it takes a muscle to shorten is not affected by the length of the lever arms, it follows that any gain in distance is a gain in speed as well

In the common form of levers seen in familiar tools and machines such as pumps scissors nut crackers and the like the resistance is applied close

Effect of Angle of Pull Besides the effect of relative length of lever arms, the action of muscles is varied by the direction in which they pull upon the lever In solving elementary problems of leverage it is usual to assume, as we have done in the examples above, that the force is applied at right angles to the lever, but in the action of muscles on the levers of the body this is the exception rather than the rule Figure 53 shows two muscles pulling at nearly a right angle, but it is plain that if the joint were in any other position they would not do so and in the positions of extreme flexion and extension of this joint they will pull at a much smaller angle Many muscles never pull an angle greater than 20 degrees

Figure 54 shows how the angle of pull changes as a muscle shortens When the bony lever is in the position *BC* the angle of pull, *DEB*, is 12 degrees, in

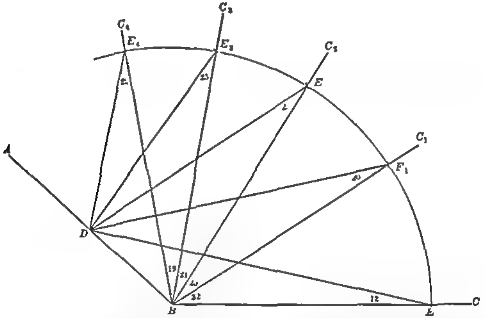

Fig 54 —Diagram to show how angle of pull changes as the bony lever is moved by the muscle *AB* is a stationary bone with axis at *B* *DE* is the muscle and *BC* the moving bone coming to positions BC_1 BC_2 etc, as the muscle shortens, the muscle coming to positions DE_1 DE_2 etc, *DEB* is the angle of pull

the position BC_1, it is 20 degrees at BC_2 25 degrees, etc The angle of pull will never be as great as a right angle unless the origin *D* is farther from the axis than the insertion *E*

The smaller the angle of pull the farther and faster will a certain amount of contraction move the bone as may be seen by Figure 54 The muscle *DE* is represented in this diagram as contracting four times each time by the same amount (one eighth of its full length) Starting from the position *BE* where the angle of pull is only 12 degrees, the first shortening turns the bone *BE* through an angular distance of 32 degrees, but as the angle of pull increases the same amount of shortening only turns it 25, 21 and 19 degrees Pulling at an angle of 10 to 12 degrees the point *E* moves more than three times as far as the muscle shortens, when the pull is at a right angle the contraction and the resulting movement are practically the same

From the Law of Levers

$$\text{Force} \times \text{Force arm} = \text{Resistance} \times \text{Resistance arm}$$
$$X \times 1 = 10 \times 12$$
$$X = 120 \text{ lbs}$$

Second Class Lever Levers of the second class always have the resistance applied between the fulcrum and the force, the resistance and the force acting in opposite directions The point where the force is applied necessarily moves through a greater distance than the point of resistance Here the force neces sary to overcome the resistance is always less than that of the resistance Speed is sacrificed in order to obtain great power This class of lever is illus trated by the wheelbarrow or a nut cracker Kinesiologists have variously presented the act of rising on tiptoe as an example of the functioning of first [1] second,[2] and third[3] class levers In static equilibrium, however any point may be chosen as the fulcrum, and the sum of clockwise and counterclockwise torques about this point will be equal Therefore the designation of the class of lever becomes arbitrary and the type of lever advocated is immaterial provided that all torques involved are considered [4]

Third Class Lever Levers of the third class have the force applied between the fulcrum and the resistance, force and resistance operate in opposite directions and the force must always be greater than the resistance A common example of a third class lever is the action of a spring closing a door The action of the biceps flexing the arm against resistance is a typical example (See Figure 53, Muscle *III*) Illustration shows how power is again sacrificed to gain greater distance and speed at *R*

A typical example would be holding a 16 lb shot in the hand with the elbow flexed so the biceps pull at an angle of 90 For further simplification we will also neglect the weight of the forearm The fulcrum is at the elbow joint If we assume the distance from the fulcrum to the insertion of the biceps to be 2 inches, and the distance of the center of the shot from the fulcrum to be 14 inches we can apply the Law of Levers and solve for the force exerted by the biceps

$$16 \times 14 = X \times 2$$
$$224 \text{ lbs} = 2X$$
$$112 \text{ lbs} = X$$

If we wish to include the weight of the forearm in our calculations we must know its weight and center of gravity If we assume the weight of the forearm and hand to be four pounds and the center of gravity to be 6 inches from the fulcrum we can calculate the torque about the elbow from this source alone

$$6 \times 4 = 24 \text{ lb force}$$

Add this to the torque of 224 exerted by the shot and we find the total torque exerted by the weight of the arm and the shot to be 248 This torque must be balanced exactly by the torque on the opposite direction resulting from the force exerted by contraction of the biceps

$$\text{Force} = \frac{\text{Torque}}{\text{Lever arm}}$$

$$\text{Force} = \frac{248}{2} = 124 \text{ lbs force exerted by the biceps}$$

let us assume that the muscle *DE*, which is pulling on the lever at an angle of approximately 27 degrees, is contracting with a force of 100 pounds In the table of sines we find the sine of 27 degrees to be 0 45399, placing these values in the formula it becomes $f = 100 \times 0.45399$, which gives 45 399 pounds as the effective force To find the force acting lengthwise of the lever we find the angle *HFE* (90 − 27 = 63) and proceed as before

$$f = 100 \times 0.89101, \text{ or } 89.101 \text{ pounds}$$

In this case therefore, the diagonal represents 100 pounds and the two sides 45 3 and 89 1 pounds

Steindler[5] properly calls the useful component of force the rotatory component because it produces rotation of the lever about its axis He designates the component of force along the length of the lever arm as the stabilizing component because in many cases it serves to stabilize the system by pulling the end of the bone more firmly into the joint In cases where a hinge joint is flexed at an angle of less than 90°, the non rotatory or stabilizing component of force no longer tends to pull the end of the bony lever into the joint but, on the contrary, tends to pull it out of the joint thereby decreasing its stability In such a case it may still be termed a stabilizing component, but it will be negative in value Stabilization is of particular importance in the case of the shoulder where the head of the humerus is held loosely in place In the absence of a relatively large stabilizing component of force certain strenuous efforts might cause the joint to dislocate In the upper range of movement where this is a definite possibility, the supraspinatus aids greatly by providing a relatively large force for this purpose In some other cases such as the hip the stabilizing component need not be large because the socket is deep and the head of the femur is held firmly in place by strong taut ligaments In many positions the weight of the body also tends to hold the head of the femur in the socket

Because the stabilizing component of force cannot be employed to do useful work in so far as the efficiency of the machine is concerned, it is so much energy wasted In any movement where conditions are such that the stabilizing force is relatively large compared to the rotatory force, the efficiency of the movement is necessarily low

Effect of Angle of Resistance While we are considering angle of pull it is well to notice that the resistance as well as the muscle may act at various angles

When the resistance is a weight it will always act vertically downward In Figure 56 the weight is shown pulling down on the bony lever at an angle of 45 degrees, when the lever is in a horizontal position this pull is at 90 degrees, but in other positions it acts at smaller and smaller angles so that its force like that of the muscle is resolved into an effective component acting at right angles to the lever and an ineffective component acting lengthwise to it

To illustrate fully how the muscular requirement is influenced by these elements of leverage and how to attack such problems let us inquire with what force a muscle acting on the elbow joint must pull to lift 10 pounds in the hand when the forearm is 45 degrees above the horizontal the muscle arm being 2 inches the weight arm 12 inches and the angle of pull of the muscle 75 degrees

The conditions of this problem are illustrated by Figure 56 Evidently the

The gain in speed and distance that a muscle secures when it pulls at a small angle is balanced by a loss of power that is illustrated in the "parallelogram of forces" diagram of Figure 55. As in the preceding figure AB is a stationary bone and BC a moving bone with the axis at B, DE is the muscle pulling at the angle DEB. The muscle pulls on its insertion at E in the direction of D, but the rigid bone BE will not permit E to move that way, but rather resolves the pull of the muscle into two forces—one of which acts in the direction EG to move the bone on its axis and the other in the direction EB to move the bone lengthwise and only serves to increase the friction in the joint at B. Now it is found experimentally that if we choose any point on DE as F, and construct the rectangle $HEGF$, with the two lines perpendicular to BC and the third line parallel to it, the length of the side EG will represent accurately the useful part of the muscle's force and HE the ineffective part

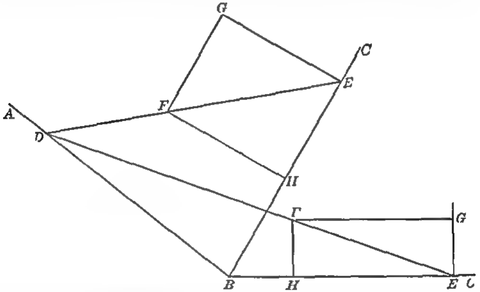

FIG. 55.—The parallelograms of forces. AB, stationary bone; BC, moving bone; B, axis; DE, muscle; BC', another position of BC; DE', taking the position DE; DEB and $DE'B$, angles of pull; $HEGF$ and $H'E'G'F'$, the parallelograms of forces. See text.

while the diagonal FE represents the entire force of pull. It is clearly seen by a look at the diagram that as the angle of pull (DEB) changes the length of the sides of the rectangle will change: with the larger angle of pull that exists when the point E is moved to E' it takes the form $H'E'G'F'$, with the relative length of sides reversed.

The relation of the side EG to the diagonal EF is constant for each size of the angle DEB and the ratios for the different sizes of the angle have been computed and can be found in the table on page 134. This ratio is called the *sine* of the angle, and the useful component for any angle can be found by multiplying the entire force of the muscle by the *sine* of the angle at which it pulls. The mathematical formula is $f = F \times s$, in which f is the effective force, F is the entire force, and s is the sine of the angle of pull.

To illustrate how this formula is applied to problems of muscular action

let us assume that the muscle DE, which is pulling on the lever at an angle of approximately 27 degrees is contracting with a force of 100 pounds In the table of sines we find the sine of 27 degrees to be 0 45399, placing these values in the formula it becomes $f = 100 \times 0\,45399$, which gives 45 399 pounds as the effective force To find the force acting lengthwise of the lever we find the angle HFE $(90 - 27 = 63)$ and proceed as before

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To illustrate fully how the muscular requirement is influenced by these elements of leverage and how to attack such problems let us inquire with what force a muscle acting on the elbow joint must pull to lift 10 pounds in the hand when the forearm is 45 degrees above the horizontal the muscle arm being 2 inches the weight arm 12 inches and the angle of pull of the muscle 75 degrees

The conditions of this problem are illustrated by Figure 56 Evidently the

weight will ac upon the lever so as to resist the action of the muscle with a force equal to 10 pounds multiplied by the sine of 45 degrees or 7 07 pounds This multiplied by its lever arm (7 07 × 12) gives 84 84 inch pounds to be overcome by the action of the muscle From the law of levers we have $f \times 2 =$ 84 84, or $f =$ 42 42 pounds This is the effective force that must be produced by the action of the muscle at an angle of 75 degrees (sine = 0 96593) We wish to find F so in the formula $f = F \times s$ we substitute the known quantities giving the formula, 42 42 = $F \times$ 0 96593 or $F =$ 42 42 — 0 96593 from which F or the whole force of contraction is 43 9 pounds

Effect of Lever Structure In applying the general principles of leverage to bones it is necessary to bear in mind that the two arms of a lever are two straight lines drawn from the two other points to the axis, in some cases these two may form one and the same straight line, but usually not In case of the humerus for example, the point of contact with the scapula that serves as the axis of the shoulder joint is an inch or more to one side of the shaft of the bone, as a result the two lever arms meet at a rather large angle, as shown in

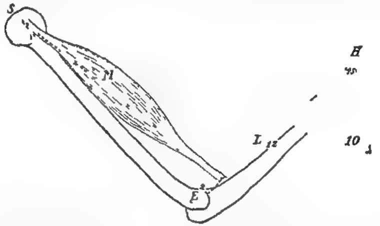

FIG 56 —Conditions of action of a muscle acting on the elbow joint to lift a weight in the hand S shoulder E elbow M, muscle H hand L lever

Figure 57 In most cases we have one principal resistance and therefore one resistance arm with several muscles acting each with its own muscle arm, making a complex lever with several forces acting on it at once The angle of the axis has no effect on the law of leverage for as long as the lever is a rigid bar it acts in the same way whether it is straight or not To solve cases of combined muscle action we may work each one out separately as if it acted on the resistance by itself and then add the results or we may multiply each force by its arm and add the products before applying the law of levers To illustrate suppose that two muscles pull on the humerus at Sp and D (Fig 57) with a force of 100 pounds each, the muscle arm at Sp being 1 inch and the angle of pull 60 degrees, the muscle arm at D 5 inches and the angle 15 degrees how much resistance will they overcome at a distance of 12 inches down the arm? The product for Sp will be 1 × 100 × 0 86603 or 86 603 the product for D will be 5 × 100 × 0 25882 or 129 41 the sum of the two is 216 013 by the law of levers $r =$ 216 013 — 12 or 18 001 pounds This is the

effective resistance, if the resistance acts at an angle less than 90 degrees, the total resistance overcome will be the number just given divided by the sine of the angle at which it acts

Very often the resistance to muscular action is the weight of a part of the body and when this is the case we must not only know the weight of the part but also its distance from the axis In all cases of this kind the weight is

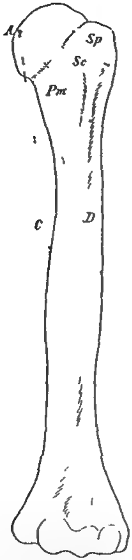

FIG 57 —The humerus to show the lever arms upon it *A* axis *Sp* lever arm of supraspinatus *Sc* of subscapularis *Pm* of pectoralis major *D* of deltoid *C* of coracobrachialis

assumed to be at the center of gravity of the part and the weight arm of the lever measured from that point These points have been worked out carefully For example the center of gravity of the whole arm is slightly below the elbow for the lower limb just above the knee etc Fischer determined the center of gravity for the various body segments [6]

TABLE 6 — Table of Sines

Degrees	*Sines*	*Degrees*	*Sines*	*Degrees*	*Sines*	*Degrees*	*Sines*
0 or 180	00000	23 or 157	39073	46 or 134	71934	69 or 111	93858
1 or 179	01745	24 or 156	40674	47 or 133	73135	70 or 110	93969
2 or 178	03490	25 or 155	42262	48 or 132	74314	71 or 109	94552
3 or 177	05234	26 or 154	43837	49 or 131	75471	72 or 108	95106
4 or 176	06976	27 or 153	45399	50 or 130	76604	73 or 107	95630
5 or 175	08716	28 or 152	46947	51 or 129	77715	74 or 106	96126
6 or 174	10453	29 or 151	48481	52 or 128	78801	75 or 105	96593
7 or 173	12187	30 or 150	50000	53 or 127	79864	76 or 104	97030
8 or 172	13917	31 or 149	51504	54 or 126	80902	77 or 103	97437
9 or 171	15643	32 or 148	52992	55 or 125	81915	78 or 102	97815
10 or 170	17365	33 or 147	54464	56 or 124	82904	79 or 101	98163
11 or 169	19081	34 or 146	55919	57 or 123	83867	80 or 100	98481
12 or 168	20791	35 or 145	57358	58 or 122	84805	81 or 99	98769
13 or 167	22495	36 or 144	58779	59 or 121	85717	82 or 98	99027
14 or 166	24192	37 or 143	60182	60 or 120	86603	83 or 97	99255
15 to 165	25882	38 or 142	61566	61 or 119	87462	84 or 96	99452
16 or 164	27564	39 or 141	62932	62 or 118	88295	85 or 95	99619
17 or 163	29237	40 or 140	64279	63 or 117	89101	86 or 94	99756
18 or 162	30902	41 or 139	65606	64 or 116	89879	87 or 93	99863
19 or 161	32557	42 or 138	66913	65 or 115	90631	88 or 92	99939
20 or 160	34202	43 or 137	68200	66 or 114	91355	89 or 91	99985
21 or 159	35837	44 or 136	69466	67 or 113	92050	90	1 00000
22 or 158	37461	45 or 135	70711	68 or 112	92718		

THE WHEEL AND AXLE

However important may be the action of muscles on bones with the latter acting as levers, this alone does not give a satisfactory explanation of the mechanics of many of the situations which arise when human motion is studied. The body also utilizes the principle of the wheel and axle. This principle is, in reality, a special case or modification of the principle of the lever. Its most important application within the body is that of either effecting or preventing rotation of a limb.

Consider Figure 58, where the circle represents a cross section of the femur. Muscle M is attached on the circumference. Contraction of muscle M tends to rotate the bone or shaft around its center O in a clockwise direction. Similarly, contraction of muscle N would rotate it in a counter clockwise direction. In the case of muscle M, the moment or torque exerted is equal to the product of the radius of the cross section times that component of the force exerted by M which is tangential to the circumference and perpendicular to the long axis of the bone.

Clockwise rotation of the limb may be effected by the contraction of muscle M accompanied by inhibition of muscle N, and vice versa. Ordinarily both muscles M and N are in a state of moderate contraction or tonus, with the torque exerted by one of the muscles balanced exactly by the torque exerted by the other. In this way the shaft of the femur, for example, is stabilized and deviations from the desired alignment are prevented. In a real situation not

two but many muscles engage in synergic action Also muscles M and N are usually not aligned perpendicularly to the long axis of the bone but more often their pull is oblique thereby providing a longitudinal component of force as well as a tangential one

Frequently a muscle is attached to a tuberosity or process This increases the torque by a local increase in the radius of the cross section of the bone Because bones are not straight and joints are not precisely aligned, the geometrical axis of the bone is not necessarily the axis of rotation When the axis of rotation of the bone is farther away than the geometrical axis from the insertion of the muscle, the torque is increased

PULLEY ACTION

The lever and the wheel and axle provide the body with means for obtaining mechanical advantage or speed and range of movement, whichever is required There is a third mechanical principle employed by the body which, although

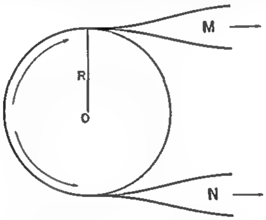

FIG 58 —The wheel and axle

it does not directly provide for mechanical advantage, does play a necessary role in the operation of the body

The pulley is a useful device often used to change the direction of a force or gain mechanical advantage as in the case of the block and tackle arrangement Only the first characteristic of the pulley is employed in the human body Tendons are often guided around joints so that when the muscle contracts the force is applied at a quite different angle The tendons which serve the fingers and toes are subject to pulley action Without this structure we would be unable to grasp anything The path of the tendon of insertion of the peroneus longus muscle illustrates the use of pulley action to change direction of applied force This tendon goes directly down the lateral aspect of the leg passes behind the external malleolus, turns forward, and thence goes to a notch in the cuboid bone which also forms a pulley and provides another opportunity for a change of direction Here the tendon turns under the foot and inserts into the first cuneiform and the first metatarsal on the opposite side There is consequently a final application of force in a direction quite different from the one originally taken

When a tendon passes over a pulley, its angle of insertion is often greater than would be the case if the pulley structure were not present. An example of pulley action used in this manner is provided by the tendon of the quadriceps femoris muscle, the patella, and the patellar ligament. This arrangement directs the force of the quadriceps femoris over the patella to the insertion of the patellar ligament on the tibia. The change of direction of the force is such that there is an increase in the rotatory component of force at the ligament's insertion and a decrease in the stabilizing component of force at the joint. Pulley action, therefore, not only changes the direction of force but also indirectly increases the effective force in certain movements.

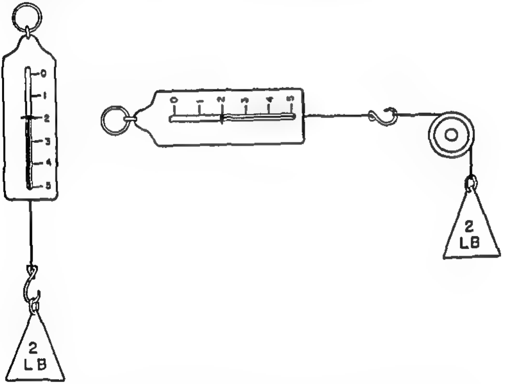

FIG. 59.—Illustrating change in direction without change in magnitude of force.

PROBLEMS

1. A small boy can exert a downward force of 50 pounds but he wishes to lift a weight of 300 pounds with a lever of the first class. If the fulcrum is placed one foot from the weight, how far from the fulcrum must he apply the force? What mechanical advantage is required?

2. A man lifts a load of 1000 pounds using the wheel and axle. If the wheel is 50 inches in diameter and the axle 4 inches in diameter, assuming no frictional loss, what force must he apply?

3. A man and a boy carry a weight of 300 pounds. It is suspended between them from a ten foot pole. If we disregard the weight of the pole, where must the weight be placed so that the man will carry twice as much as the boy?

4. A lever of the second class is 10 feet long. It is used to lift a weight of 500 pounds. Where must the weight be placed if the maximum force that can be employed is 75 pounds?

5 What is the greatest load a man can lift with a wheelbarrow if he can exert an upward force of 300 pounds at the handles which are five feet from the axle, if the load is two feet from the axle?

6 A ten pound weight is held in the palm of the hand and the elbow is flexed at 90° If the weight is 14 inches from the elbow joint and the biceps is inserted 1½ inches from the elbow joint, what must be the effort exerted by the biceps?

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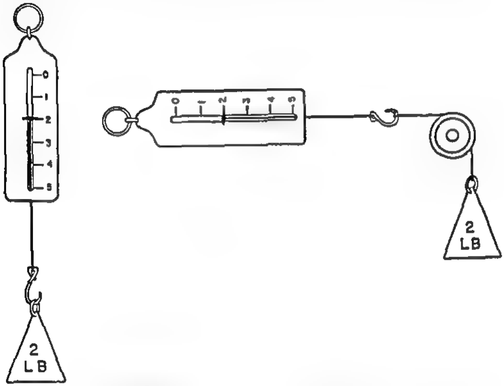

FIG 59 —Illustrating change in direction without change in magnitude of force

PROBLEMS

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4 A lever of the second class is 10 feet long It is used to lift a weight of 500 pounds Where must the weight be placed if the maximum force that can be employed is 75 pounds?

two symmetrical halves, right and left (Fig 60) Any parallel plane is known as a *parasagittal* or anterior posterior plane

2 A *frontal* or coronal plane, also vertical but passing through the body from side to side and at a right angle to the sagittal plane, dividing the body into equal anterior and posterior halves (Fig 61) The line of intersection of these two planes is called the *gravital line*

3 The *horizontal* or traverse plane which passes through the body at the height of the center of gravity (Fig 62)

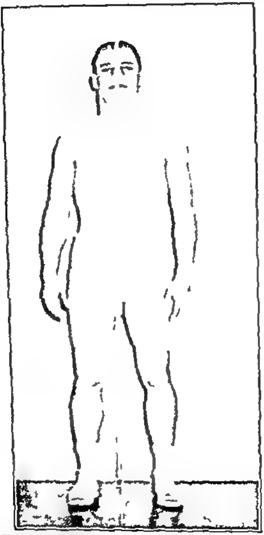

Fig 60 —Sagittal plane (Photo by Pierson)

The center of gravity is the one point where all three planes intersect This location holds true for just this specified position If an arm is raised or one stoops to tie a shoe lace the center of gravity accordingly changes its position If a person carries a load the combined center of gravity must be considered rather than taking them separately If a load is carried under one arm the trunk of the body leans away from the load so that the combined center of gravity is brought over the base of support If a weight is carried in the arms in front of the body we compensate for the new center of gravity by leaning

Chapter 8

Center of Gravity and Equilibrium

WHEN an object lies upon the ground or any flat surface, the force of gravity acts on every portion or particle These forces are all parallel are directed toward the earth s center and when added vectorially the resultant is a single force acting through the center of mass and equal to the weight of the object The center of mass or gravity is defined as that point where the total weight of the object can be considered to be concentrated In a frictionless environment any force applied to the center of gravity regardless of its direction can produce only rectilinear motion never rotatory In the case of any rigid symmetrical body with uniform density such as a golf ball or a brick the geometrical center is also the center of gravity If however the object has an irregular shape or if its density is not the same throughout it is unlikely that the geometrical center and the center of gravity will coincide

The human body has an irregular shape and the relative density of its component parts may vary considerably Further its gross configuration may be changed at will The center of gravity then does not occupy some specific position but its position depends upon the momentary relative disposition of the trunk and limbs It becomes necessary then when the center of gravity of the human body is mentioned to refer to some specific position

In the normal erect standing position with the arms hanging at the sides the center of gravity of adult males is according to many investigators approximately 56 to 57 per cent of the total height from the floor The center of gravity of adult females is somewhat lower being about 55 per cent of their standing height There are relatively large deviations between individuals due to differences in physique The center of gravity of small children and adolescents is higher because of the disproportionate size of the head and thorax and the relatively small legs In general the younger the child the higher its center of gravity

Anatomical Reference Planes The location of the center of gravity in the standing position can be expressed by referring to three reference planes used in anatomical descriptions

1 The *cardinal sagittal* plane which divides the body vertically into

Stable Equilibrium An object at rest may have great stability like a brick lying flat on the ground which requires a considerable force properly applied to overturn it In order to destroy the stability of an object it must be tipped so that a line dropped vertically from the center of gravity (gravital line) falls outside the base of support If the center of gravity is low and the base of support is broad, much work must be done to lift and move the center of gravity so that it will fall outside the base

This principle is fundamental in automotive design where engineers are constantly striving to increase stability and safety The football linesman

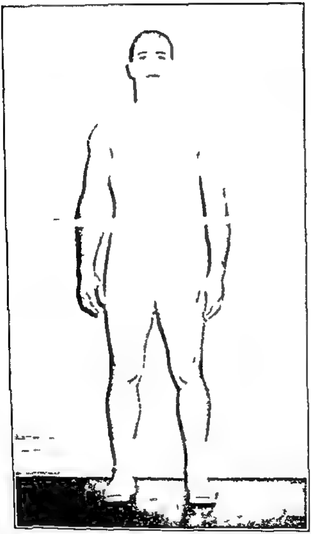

FIG 62 —Horizontal or transverse plane (Photo by Pierson)

may increase his stability in two ways first by keeping as low as possible and second by increasing the area of support The feet can be spread only a reasonable distance otherwise he will lose traction and slip If his feet are in the most advantageous position and he has one hand on the ground, the base of support is a triangle If he places both hands on the turf, his base of support is now rectangular and the increased area provides greater stability but at a sacrifice of maneuverability The determination of the optimal position is a problem common to many sports

backward A hiker with a heavy pack on his back leans forward in order to keep the combined center of gravity over the base of support thereby decreasing the muscular effort required to maintain equilibrium

When standing the gravital line is of importance, not only in the maintenance of stable equilibrium, but is also important in the correction of some types of faulty posture Normally the gravital line falls half way between the weight bearing areas of the ball of the foot and the heel If the line is allowed to fall too far forward or backward, bringing it nearer the margin of the base of support, unnecessary muscular effort is required to overcome the torque produced and to prevent falling

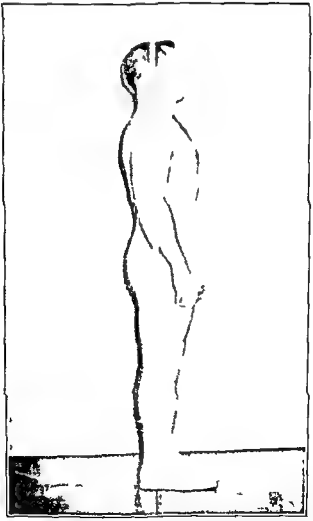

FIG 61 —Frontal or coronal plane (Photo by Pierson)

EQUILIBRIUM

An object is in a state of equilibrium or rest when the resultant of all forces acting upon it is zero There can be no unbalanced force A force from any direction must be exactly balanced by an equal force from the opposite direction An unbalanced force will cause either rectilinear or rotatory motion depending upon the point of application

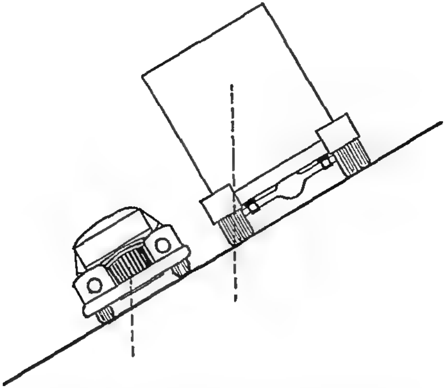

FIG 64 —Relative stability The gravital line of the automobile falls well within the base of support but that of the truck falls at the very edge of its base of support and it is unstable

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Unstable Equilibrium If an object like a baseball bat is balanced on one end its equilibrium is easily destroyed It requires only a slight touch to raise and shift the center of gravity so that the gravital line will fall outside the base of support and cause it to topple A child walking the top of a fence is an example of unstable equilibrium

Neutral Equilibrium On a level surface a ball is in neutral equilibrium No matter how much it is pushed about and overturned its center of gravity is not raised and the gravital line still falls directly on the base of support, even though it is only a point

Dynamic Equilibrium Static equilibrium can be summarized briefly by stating that stability of any object is dependent upon a low center of gravity and a large and properly placed base of support Dynamic equilibrium (balance while in motion) is the result of the action of many forces and gravity which is a primary consideration in static equilibrium may be only one of several interacting forces When a person moves in any direction the force exerted by the driving leg propels the center of gravity so that the gravital line temporarily falls outside the base of support An immediate adjustment is made to correct the situation and to prevent falling by stepping in the direction of motion broadening the base of support so that the gravital line again falls within its boundaries This is the usual pattern of recovery followed by the person walking or running in a straight line When rounding a curve at high speed a runner leans toward the inside of the turn Centrifugal force would if unopposed, tend to cause his center of gravity to shift beyond his base of support laterally To prevent this the runner leans toward the inside thus keeping his center of gravity inside the outer limits of his base of support and making it possible for him to exert centripetal force against his center of gravity This counteracts centrifugal force developed because of the constant changing direction as he rounds the turn

When one is pushed equilibrium is preserved by taking a step in the direction of motion thereby broadening the base of support If the new position is to be maintained a very wide step must be taken to provide an outer limit well beyond the gravital line From here force can be applied in the opposite direction to that of the original external force and thereby preserve equilibrium

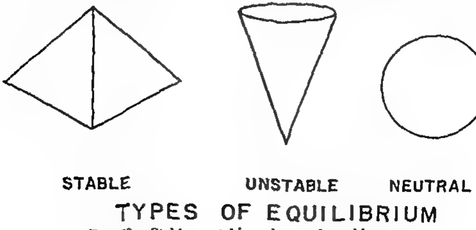

Fig 63 —Stable unstable and neutral equilibrium

and the joint permits the outer end of the clavicle to be moved up and down, forward and backward, or any combination of these movements, it also permits slight rotation of the clavicle on its long axis The capsular ligament of the joint is strengthened by thickened bands at the front and rear, injury of the joint is further prevented by a ligament, called *intraclavicular*, which joins the two clavicles and by a ligament called the *costoclavicular*, which connects the under surface of each clavicle with the rib below it (Fig 67)

The outer end of the clavicle is joined to the anterior border of the acromion by the *acromioclavicular* ligament, strengthening the capsular ligament on the upper side The main protection against injury to the joint is the *coracoclavicular* ligament two strong bands of fibers connecting the top of the coracoid with the under surface of the clavicle

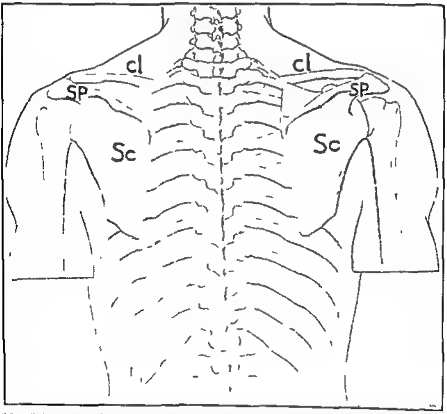

FIG 65 —The shoulder girdle rear view *Sc* scapula *cl*, clavicle *Sp* spine of scapula (Richer)

All movements of the shoulder girdle may be properly called movements of the scapula since the position of the clavicle does not permit of its moving independently These movements always involve both of the joints just described the clavicle moving so as to allow the scapula to assume its proper relation to the chest wall

In everyday life most movements of the scapula are closely integrated with and secondary to movements of the arm The scapula serves as a mobile base from which the arm operates Whatever action or position is required of the arm to accomplish a given task the scapula moves to align the glenoid fossa so it will be in the best possible position to receive the head of the

Chapter 9

Movements of the Shoulder Girdle

THE shoulder girdle* in man consists of two bones the *clavicle* and the *scapula* The bones of the arm are joined to the scapula and the clavicle connects the scapula with the main part of the skeleton The clavicle extends horizontally sidewise and slightly backward from its junction with the top of the sternum and joins the scapula at the tip of the shoulder The scapula lies on the outer surface of the chest at the back, extending in normal position from the level of the second rib to that of the seventh, with its posterior border about 2 inches distant from the spinal column (Fig 65)

The clavicle which is about 6 inches long appears straight when viewed from the front, but when seen from above it is curved like an italic *f* with the inner end convex to the front and the outer end convex to the rear The upper surface is smooth and the under surface rough, the inner end is the thicker and the outer end more flattened (Fig 66)

The scapula is a flat triangular bone with two prominent projections upon it the *spine* from the rear and the *coracoid* from the front The spine has a flattened termination called the *acromion* A deep impression above is named from its position the *supraspinous* fossa while the shallower one below is called the *infraspinous* fossa The humerus articulates with a shallow socket at the outer angle just below the acromion which is known as the *glenoid* fossa The greatest length of the scapula in man is from above downward in the adult about 6 inches its greatest breadth is horizontal, about 4 inches This is a marked exception to the general rule in vertebrate animals most animals having the long axis of the scapula in line with its spine so that the glenoid fossa is at the end of the scapula instead of at the side

The clavicle is joined to the sternum by a double joint the two bones being separated by a cartilage with one articulation between the sternum and the cartilage and another between the cartilage and the clavicle The cartilage serves as an elastic buffer in case of shocks received at the arm or shoulder

* Some kinesiologists object that the term shoulder girdle is a misnomer since the scapulae are not linked to each other See Laurence Jones The Shoulder Joint California Med *84 185–192 1956 However the term is so generally used that it is probably futile to* attempt to discard it now

and the joint permits the outer end of the clavicle to be moved up and down, forward and backward, or any combination of these movements, it also permits slight rotation of the clavicle on its long axis The capsular ligament of the joint is strengthened by thickened bands at the front and rear, injury of the joint is further prevented by a ligament, called *intraclavicular*, which joins the two clavicles and by a ligament called the *costoclavicular*, which connects the under surface of each clavicle with the rib below it (Fig 67)

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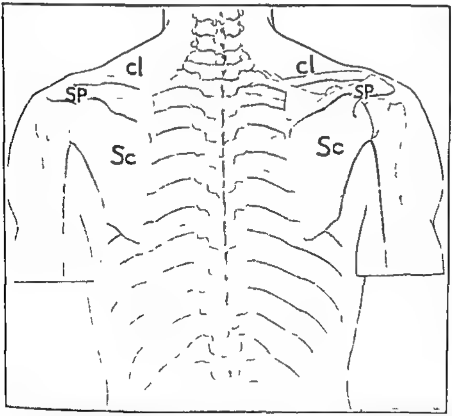

FIG 65 —The shoulder girdle, rear view *Sc*, scapula *cl* clavicle *Sp*, spine of scapula (Richer)

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humerus The mobility of the scapula makes possible a much wider range of movement of the arm than it would have otherwise

The fundamental movements of the scapula may be classified as follows

1 Backward toward the spinal column (adduction) and sideward and forward away from it along the surface of the ribs (abduction), this movement may extend through 6 inches or more being limited posteriorly by contact of the two scapulae at the median line and anteriorly by the resistance of the posterior muscles

2 Upward movement of the entire scapula (elevation) and downward (depression), this may take place through 4 or 5 inches

3 Rotation on a center so as to raise the acromion and turn the glenoid fossa upward (rotation up) and the reverse (rotation down) which may take

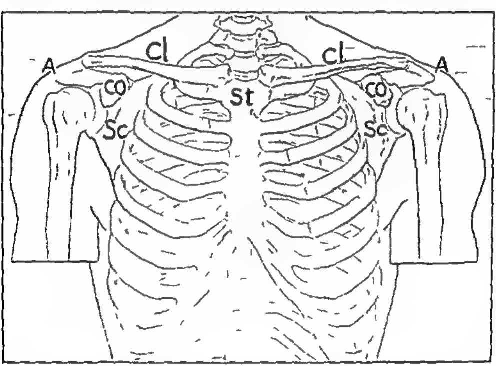

Fig 66 —Shoulder girdle front view *Sc* scapula *cl* clavicle *co* coracoid *A* acromion *St* sternum (*Richer*)

place through an angle of 60 degrees or more Rotation of the scapula is associated with all upward and downward movements of the arm

Since the clavicle is attached to the sternum which is comparatively stationary it is evident that the acromion must always move in a curve with the clavicle as a radius Since the clavicles are horizontal in normal position any movement involving raising or lowering of the acromion will therefore narrow the distance between the two shoulders Since the clavicles normally slant backward somewhat evidently all adduction of the scapula will narrow the shoulders and abduction will widen them until the two clavicles fall in one line after which further abduction will narrow them again The action of the clavicle will also cause the acromion to go toward the rear as the scapula is moved toward the spinal column

The following six muscles connect the shoulder girdle with the main skeleton, hold it in normal position and give rise to the movements just described Anterior subclavius pectoralis minor, serratus anterior Posterior levator scapulae trapezius, rhomboid

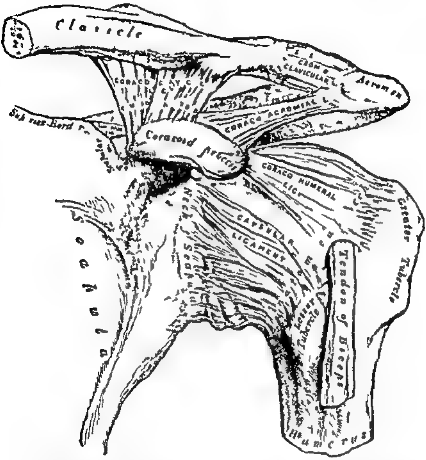

FIG 67 —The left shoulder and acromioclavicular joints and the proper ligaments of the scapula (*Gray s Anatomy*)

TRAPEZIUS

The trapezius muscle is a flat sheet of muscular fibers located on the upper part of the back and lying immediately beneath the skin

Origin Base of the skull ligament of the neck and the row of spinous processes of the vertebrae from the seventh cervical to the twelfth dorsal inclusive (Fig 68)

Insertion. Along a curved line following the outer third of the posterior border of the clavicle the top of the acromion and the upper border of the spine of the scapula (Figs 210 and 212)

Innervation The spinal accessory nerve (spinal portion of 11th cranial nerve) and branches from anterior rami of 3rd and 4th cervical nerves

Structure Best studied in four parts passing from above downward

Part one is a thin sheet of parallel fibers starting downward from the base of the skull and then curving somewhat sideward and forward around the

neck to the insertion on the clavicle It is so thin and elastic that when it is relaxed one or two finger tips can be pushed down behind the outer third of the clavicle with ease stretching the muscle before it and forming a small pocket when it contracts the fingers are lifted out and the pocket disappears This enables us to test the action of part one of the trapezius which is too thin to be seen and felt in the usual way

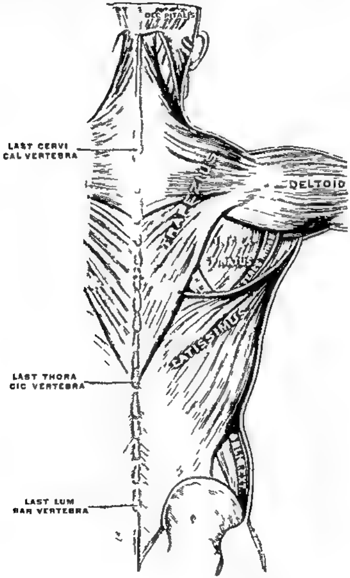

FIG 68 —Trapezius and latissimus

Part two extending from the ligament of the neck to the acromion is a much thicker and stronger sheet of fibers tendinous at the origin and con verging to the narrower insertion

Part three is similar to part two and still stronger and includes the fibers that arise from the seventh cervical and the upper three dorsal vertebrae these converge somewhat to the insertion on the spine of the scapula

Part four the lowest is not so strong as the two middle portions but

stronger than the first; the fibers converge from their origin on the lower dorsal vertebrae to join a short tendon attached to the small triangular space where the spine of the scapula ends, near the vertebral border.

When the head is free to move, contraction of part one of the trapezius will lower the back of the skull and turn it to the side, since the skull is poised freely on a pivot at its base; this *will tilt the chin up and turn the face to the* opposite side. When part one of right and left sides contract at once, evidently they will neutralize the tendency to rotate the head and will tilt the chin up with double force. However, electromyographic studies indicate that the trapezius functions in such movements as an accessory muscle, and is involved only when they are performed against strong resistance.[1] The upper trapezius

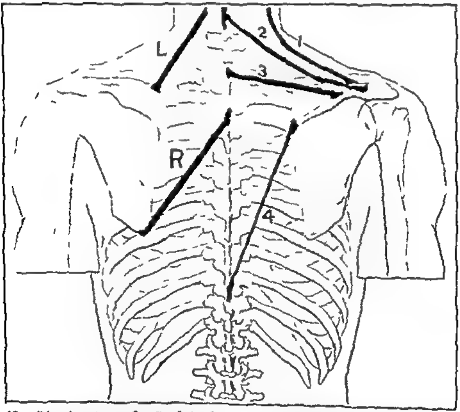

FIG. 69.—The direction of pull of the four parts of the trapezius on the right and of the levator and rhomboid on the left. *L*, levator; *R*, rhomboid.

levator scapulae and upper digitations of the serratus anterior form a unit which provides passive support of the shoulder, *elevation* of the shoulder and the upper component of the force couple necessary for scapular rotation.[2]

With the head held still and the shoulder girdle free to move, contraction of part one of the trapezius will elevate the clavicle and scapula, but with little force because the muscle is thin and weak.

Action of part two will elevate, *upward rotate*, and assist with *adduction* of the shoulder girdle.

Part three pulls in nearly a horizontal line upon the spine of the scapula, drawing it toward the spinal column. It is a prime mover for adduction of the scapula.

Subjects who have lost the use of the levator have the shoulder depressed the deformity being most marked when both levator and second part of the trapezius are lacking Loss of these two main supports is characterized by a thin neck and sloping shoulders If the trapezius is paralyzed the levator scapulae form a prominent ridge on the neck when in action

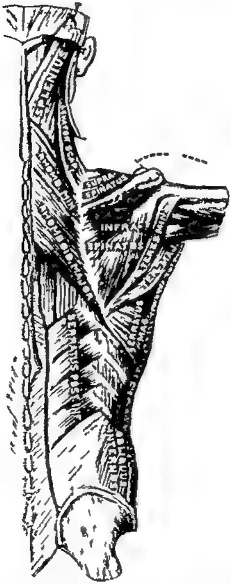

FIG 71 —Muscles of second layer of the back and those on the back of the shoulder

RHOMBOID

The rhomboid is named from its shape that of an oblique parallelogram It lies beneath the middle of the trapezius (Fig 71)

Origin The row of spinous processes of the vertebrae from the seventh cervical to the fifth dorsal inclusive

Insertion The vertebral border of the scapula from the spine to the inferior angle (Fig 212)

Innervation The dorsal scapular nerve from the brachial plexus The fibers come from the 5th cervical nerve

Structure Parallel fibers extend diagonally downward and sideward from the origin The upper part usually separate from the lower and described separately as the "rhomboideus minor" is thin and weak, while the lower part is thick and strong The attachment to the scapula is peculiar, the fibers joining a tendon of insertion that is scarcely attached to the scapula at all for its upper two thirds, sometimes the middle half is entirely free from the edge of the scapula, bringing the pull to bear on the lower angle alone

Action The structure of the rhomboid and its manner of insertion gives it a line of pull as shown in figure 69, considerably different from what is suggested by its general location and appearance It adducts the lower angle of the scapula without adducting the upper angle at all, and so rotates the scapula downwards The action of the rhomboid when combined with that of the latissimus is to turn the scapula so that the glenoid fossa is turned downward to such a degree that the arm cannot be raised above the level of the shoulder

The part played by the rhomboid in maintaining normal posture as shown by defective cases, consists in moderating the upward rotation of the scapula produced by the trapezius so as to keep the acromion down and in holding the lower angle close to the ribs Subjects who have lost the use of the rhomboid have this angle of the scapula projecting conspicuously from the back with a deep gutter beneath its edge—a position due to the pull of muscles that attach to the upper part of the bone

Since downward rotation of the scapula usually accompanies any adduction or extension of the humerus the rhomboids will act whenever these movements are performed forcefully or against gravity

SERRATUS ANTERIOR

This muscle named from its serrated or saw toothed anterior edge, lies on the outer surface of the ribs at the side, covered by the scapula at the rear and the pectoralis major in front It lies immediately beneath the skin for a space a little larger than the hand just below the axilla or armpit, its five lower sections showing plainly through the skin when the arm is raised against resistance, as in figure 73

Origin The outer surfaces of the upper eight or nine ribs at the side of the chest

Insertion The anterior surface of the vertebral border of the scapula, from the upper to the lower angle (Figs 72 and 211)

Innervation Long thoracic nerve from anterior branches of 5th 6th and 7th cervical before they enter the brachial plexus

Structure In two separate parts, the upper and lower The upper part includes the fibers arising from the three upper ribs and diverging slightly to be inserted along the whole length of the scapula below the spine the lower part is fan shaped the fibers arising from the lower six attachments on the ribs converging to be inserted together at the inferior angle The lower part is thicker and stronger than the upper

Action The fibers of the serratus extend too nearly lengthwise of the ribs to exert much pull to move them unless the scapula is elevated Its upper

Subjects who have lost the use of the levator have the shoulder depressed the deformity being most marked when both levator and second part of the trapezius are lacking Loss of these two main supports is characterized by a thin neck and sloping shoulders If the trapezius is paralyzed, the levator scapulae form a prominent ridge on the neck when in action

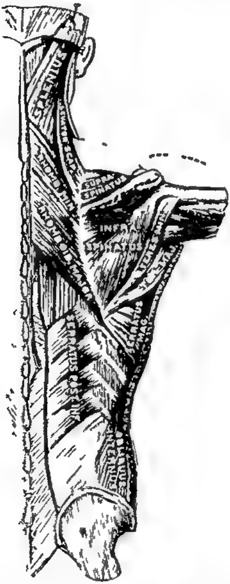

FIG 71 —Muscles of second layer of the back and those on the back of the shoulder

RHOMBOID

The rhomboid is named from its shape that of an oblique parallelogram It lies beneath the middle of the trapezius (Fig 71)

Origin The row of spinous processes of the vertebrae from the seventh cervical to the fifth dorsal inclusive

Insertion The vertebral border of the scapula from the spine to the inferior angle (Fig 212)

rhomboids and pectoralis major[5] Weakness of this muscle may be partly compensated for by hypertrophy of the lower part of the trapezius In the case of paralysis, winged scapulae have been corrected by transplanting the pectoralis minor, the pectoralis major, the rhomboids, the teres major, or other muscles[6]

Study of the serratus on the normal living body shows its action in a very clear and interesting way Whenever the subject pushes or reaches forward the scapula can be seen and felt to glide forward over the surface of the chest, and the distance it moves is surprising to all who have not observed it before When the arms are raised the trapezius can be felt to contract as soon as they

FIG 73 —The lower part of the serratus magnus in action The saw toothed shape of its lower front margin is shown plainly where it attaches to the ribs Only five saw teeth show the upper ones lying beneath the pectoralis major

begin to move but one can also see that this contraction does not rotate the scapula the lower serratus does not begin to contract until the arms have been raised through at least 20 degrees and sometimes through 45 degrees This can be tested by placing the fingers on the lower angle of the scapula and noticing when it begins to move forward

Another interesting case in which the lower serratus fails to act when it would be of use is when a weight is lifted or carried on the shoulder Although the lower serratus can lift the acromion with great force as we have seen it never acts in lifting with the shoulder or carrying a heavy weight on it the work in this case being done by the middle trapezius and levator so long as

fibers are well situated for abducting the scapula forward as a whole, without rotation The lower part of the muscle is in a position to produce vigorous rotation upward by drawing the inferior angle of the scapula forward These lower fibers are well placed to associate with the trapezius in turning the scapula upward

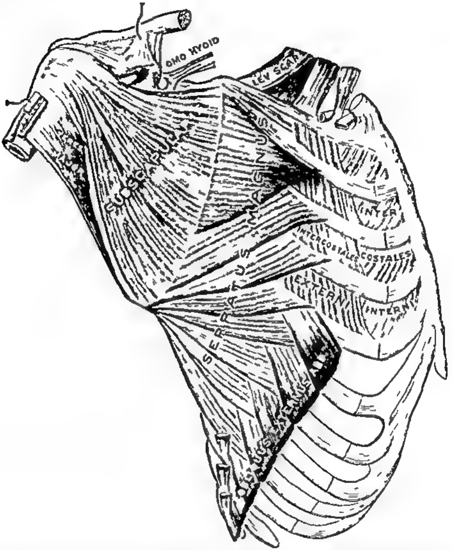

Fig 72 —Serratus magnus subscapularis and teres major Notice that the clavicle is cut apart and the scapula turned back away from the chest wall

Loss of the serratus has little effect on habitual posture of the scapula but it interferes seriously with forward movements of the shoulder and arm Subjects lacking the serratus find it difficult or impossible to elevate the arm above 100 degrees [4] and when they try to do so the vertebral border of the scapula projects backward (winging of the scapula) instead of lying close to the chest wall as it does when the serratus acts normally in the movement Generally the shoulder is displaced forward and drops to some extent This may be accompanied by painful tightness of certain antagonists, such as the

combination of abduction and downward rotation of the scapula It can also be seen that the pull of the pectoralis minor, by prying across the chest tends to lift the vertebral edge and especially the lower angle of the scapula away from the ribs This is sometimes called winged scapula or upward tilt

When the scapula is held still it is evident that action of this muscle will lift on the middle ribs especially when the shoulder is raised in preparation for it, as one unconsciously does in taking a deep breath

While normally the pectoralis minor is deeply covered, Duchenne reported cases in which, because of complete atrophy of the pectoralis major, it lay immediately under the skin and could be stimulated by electric current The isolated action secured in this way is the same as that stated above It is possible in favorable subjects to feel the contraction of the pectoralis minor through the muscle that covers it by proceeding as follows have the subject hold the arms close to the sides and a little to the rear, which inhibits any action of the pectoralis major, then have him inhale deeply, first lifting the shoulders slightly This puts the pectoralis minor into vigorous action and its lateral swelling may be felt and even seen as it lifts the relaxed tissue covering it

To summarize, it may be said that the pectoralis minor acts in deep and forced breathing but probably not in quiet breathing it is placed in a position to help in all movements involving abduction and downward rotation of the scapula which occurs in striking forward and downward as in chopping and also in supporting a part of the body weight on the arms The pectoralis minor along with trapezius 4 prevents upward displacement of the shoulder girdle when the arm exerts downward pressure against resistance In most of these cases actual test of its action is rendered impossible because of the contraction of the large muscle covering it

SUBCLAVIUS

This is the smallest of this group of muscles located as its name indicates beneath the clavicle (Fig 74)

Origin The upper surface of the first rib, just where it joins its cartilage

Insertion A groove extending along the middle half of the under side of the clavicle

Innervation By a nerve from the brachial plexus the fibers coming from the 5th and 6th cervical nerves

Structure Fibers radiating fanwise from the small tendon of origin to the much wider insertion

Action The action of the subclavius can only be inferred from its position as it is neither readily felt nor stimulated from without It is in a position to depress the clavicle but its small size and angle of insertion indicates that its torque for depression must be negligible Since the direction of its pull deviates only slightly from the long axis of the clavicle its most important function is to pull the clavicle medially protecting the sterno clavicular joint from separation in such activities as hanging by the hands

POSTURE OF THE SHOULDERS

The shoulder girdle is so freely movable that its habitual position depends on the relative tension of the six muscles discussed above together with that

the arm hangs at the side As soon as the arm is raised 30 degrees or more from the side it at once springs into action This shows a reason why one who carries a heavy weight on the shoulder finds it restful to hold the arm in various positions—sometimes down by the side and sometimes raised

PECTORALIS MINOR

A small muscle located on the front of the upper chest covered by the pectoralis major

Origin The outer surfaces of the third fourth and fifth ribs at a point a little sideward from their junction with the costal cartilages (Fig 74)

Insertion The end of the coracoid

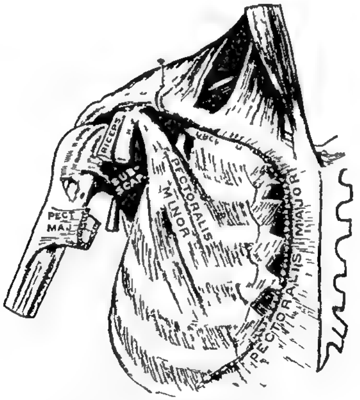

Fig 74 —The pectoralis minor and subclavius

Innervation The medial anterior thoracic nerve originating in the brachial plexus The fibers are from the 8th cervical and 1st thoracic nerves

Structure Three groups of nearly parallel fibers that converge to join a single small tendon at the upper end

Action The line of pull of the pectoralis minor may be represented on a mounted skeleton by a rubber band stretched from the coracoid to the fourth rib at a point about an inch from its junction with the costal cartilage When the scapula is in normal position the direction of pull on the coracoid will be seen to be forward downward and inward at nearly equal angles The inward pull is prevented from acting on the scapula by the position of the clavicle so that contraction of the muscle is calculated to produce a

tone of the trapezius, levator scapulae, and rhomboid, and at the same time stretch the muscles that have become shortened The prevention of postural defects is a recognized aim of the physical educator and the corrective therapist Because the nature of classroom work is such that it tends to cause round shoulders, the physical educator should include in the program exercises or sports which are calculated to prevent this condition Among the best exercises for daily use is the one shown in Figure 75 The arms are raised sideward until slightly above the level of the shoulders and then the elbows are bent and the finger tips placed against the back of the neck, which is held vigorously erect the elbows are held back strongly The position is held long enough to insure an accurate position and complete contraction of the mus cles, then the arms are returned to the sides through the same path and the

Fig 76 —A corrective exercise for abduction of the shoulders

movement repeated several times A second efficient corrective for abducted scapulae is pictured in Figure 76 The elbows are completely flexed, the entire arm is held horizontal and the elbows are drawn strongly backward Tra pezius and deltoid hold up the arm and drawn it back while the lower serratus rotates the scapula tending to shorten and increase the tone of these muscles while stretching the pectorals Another good exercise consists in strong adduction of the scapulae and outward rotation of the arms

A crucial factor in obtaining value from these exercises is the forcefulness of the scapular adduction Only in the final phase of the movement do the adductors contract sufficiently to stretch the abductors An example of insuf ficient contraction is seen in Figure 77

Some instructors advocate stretching the abductors by such exercises as skinning the cat and the corner exercise In the latter the subject faces a

produced by the pectoralis major and latissimus dorsi, which act indirectly on it through the arm Whenever some of these muscles are absent or inactive because of disease when the clavicle or scapula is deformed by disease or accident or when any of the muscles fail for any reason to exert the right amount of tension abnormal posture of the shoulders is the result

It is generally assumed by anatomists as previously stated, that for normal posture of the shoulder girdle the clavicles should be approximately horizontal, which places the scapulae at a height extending from the second to the seventh rib, and that they should lie flat against the chest wall on the back The most common defect in the position of the shoulder girdle is abducted scapulae This is objectionable because it weakens the support which the coracoid should give to the pectoralis minor and thus reduces the tension that muscle should exert on the ribs If the scapula is stabilized by the rhomboids and the trapezius the pectoralis minor exerts a direct lifting force upon the

FIG 75 —An exercise used for correction of habitual abduction of the scapulae

third fourth and fifth ribs and an indirect force upon the others In the absence of good scapular stabilization this muscle may tend to shorten and pull downward upon the coracoid

Abduction of the scapula as a fault of posture most often results from continuous occupation with the arms held in front of the trunk In writing sewing holding a book in position to read and numberless other occupations the arms and shoulders are held forward by continuous contraction of the serratus pectoralis major and minor while the trapezius, rhomboid and levator are relaxed to permit the scapulae to move forward This gradually tends to make the anterior muscles permanently shorter, while lengthening the posterior muscles After a time the scapulae can be brought to the normal position only with difficulty and this difficulty gradually becomes greater until the normal position becomes impossible

Faulty shoulder posture of this nature can be prevented by frequent participation in sports or exercises which will develop shorten and increase the

tone of the trapezius levator scapulae, and rhomboid and at the same time stretch the muscles that have become shortened The prevention of postural defects is a recognized aim of the physical educator and the corrective therapist Because the nature of classroom work is such that it tends to cause round shoulders the physical educator should include in the program exercises or sports which are calculated to prevent this condition Among the best exercises for daily use is the one shown in Figure 75 The arms are raised sideward until slightly above the level of the shoulders and then the elbows are bent and the finger tips placed against the back of the neck which is held vigorously erect the elbows are held back strongly The position is held long enough to insure an accurate position and complete contraction of the muscles then the arms are returned to the sides through the same path and the

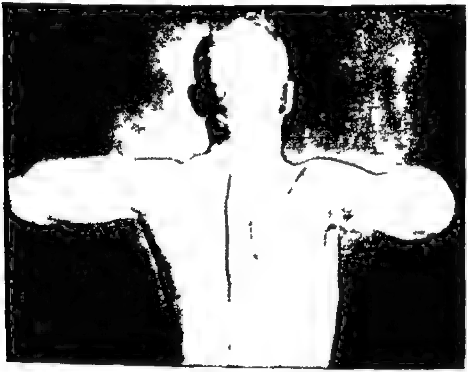

Fig. 76 —A corrective exercise for abduction of the shoulders

movement repeated several times A second efficient corrective for abducted scapulae is pictured in Figure 76 The elbows are completely flexed the entire arm is held horizontal, and the elbows are drawn strongly backward Trapezius and deltoid hold up the arm and draw it back while the lower serratus rotates the scapula tending to shorten and increase the tone of these muscles while stretching the pectoral Another good exercise consists in strong adduction of the scapulae and outward rotation of the arms

A crucial factor in obtaining value from these exercises is the forcefulness of the scapular adduction Only in the final phase of the movement do the adductors contract sufficiently to stretch the abductors An example of insufficient contraction is seen in Figure 77.

Some instructors advise stretching the abductors by such exercises as "skinning the cat" and the "corner stretch". In the latter the subject faces a

corner of the room, reached forward and upward and places the palms against the wall and proceeds to stretch by letting gravity and force from the feet push the chest toward the corner It should be noted that the adductors do not contract during this process, further, this passive stretch of the ab ductors may initiate a myotatic or stretch reflex in the abductors resulting in their reflex contraction Such an exercise may not be effective as a method of strengthening the adductors or stretching the abductors and may also strain the abductors

Another common error is to exercise with pulley weights ('chest weights) while standing with the back toward the pulley apparatus In this position forward and backward movements of the arms and scapulae are the result of concentric contraction and eccentric contraction, respectively of the shoulder

FIG 77 —The Swedish exercise shoulders firm or arms bend The position of the right arm illustrates a common fault the hand is not held back far enough to give complete adduction of the scapula

girdle abductors while the adductors remain relaxed This type of exercise tends to accentuate the defect not to correct it

Habitually abducted scapulae are often associated with forward head and kyphosis in the thoracic or cervical spine In corrective exercise therefore attention should be given to the total postural condition as well as to the specific musculature involved in the abduction of the scapulae

A marked projection and upward tilt of the lower angle of the scapula often known as winged scapula is usually due as has already been observed to a deficiency in the action of the rhomboid and serratus anterior and to a shorten ing of the pectoralis minor In mild cases the exercise of Figure 77 is a good corrective the effort to hold the elbows down giving vigorous but not strain

ing work for the rhomboid, while a forceful effort to hold the hands back will stretch the pectoralis minor As a general principle it is well to remember that exercises involving elevation of the humerus give work for the trapezius rather than for the rhomboid, while the reverse is true of exercises involving depression of the humerus A further study of this point will be made in the next chapter

Unequal height of the shoulders may be the result of unequal development of the shoulder girdle musculature on the right and left sides, or of unilateral paralysis (partial or complete) of shoulder girdle muscles Most often another cause will be discovered a lateral curvature of the spine which in turn may be caused by unilateral short leg unilateral flat foot, and other defects at a lower level Obviously, it is essential to determine whether the unequal shoulder height is caused by a local or by a remote condition

DIRECT ANTAGONISTS

Two muscles or parts of muscles are sometimes called *direct antagonists* of each other if all of the actions of one are opposite to all of the actions of the other, and vice versa Physical therapists sometimes find a practical application for knowledge of direct antagonisms in the shoulder girdle Among shoulder girdle muscles the following direct antagonisms may be identified

1 Trapezius II (upward rotation elevation and adduction) is directly antagonistic to the pectoralis minor (downward rotation depression and abduction)

2 The rhomboid (downward rotation and adduction) is directly antagonistic to the serratus anterior (upward rotation and abduction)

3 Both the levator and trapezius I (elevation) are directly antagonistic to the subclavius (depression)

HELPING SYNERGISTS

When two muscles in simultaneous contraction both perform one action while mutually neutralizing all the rest of each other s actions, they are said to be *helping synergists* The following helping synergies may be identified among the muscles of the shoulder girdle

1 Trapezius II and trapezius IV both perform adduction and upward rotation while their respective tendencies to perform elevation and depression are mutually neutralized

2 Trapezius II and the serratus anterior both perform upward rotation while their respective tendencies to perform adduction and abduction are mutually neutralized

3 Trapezius II trapezius IV and the rhomboid all perform adduction The tendency of trapezius II and trapezius IV to perform upward rotation is neutralized by the tendency of the rhomboid to perform downward rotation and vice versa

4 Trapezius IV and the pectoralis minor both perform depression The tendency of trapezius IV to perform upward rotation and adduction is neutralized by the tendency of the pectoralis minor to perform downward rotation and abduction and vice versa

More complicated combinations may be worked out if more than two muscles are considered or if additional muscles are introduced to contribute

only a stabilization or fixation function For example both the serratus anterior and the pectoralis minor perform abduction The tendency of the serratus anterior to perform upward rotation is neutralized by the tendency of the pectoralis minor to perform downward rotation, and vice versa But the pectoralis minor, upon contraction, also tends to perform depression—this could be neutralized by introducing a contraction of the levator scapulae, whose only function in this situation would be elevation From the appropriately graded contraction of these three muscles pure abduction would result As a second example the rhomboid and the pectoralis minor both perform downward rotation in the "up phase" of chinning while their respective tendencies to perform adduction and abduction are mutually neutralized The pectoralis minor tends also to perform depression, which the rhomboid cannot neutralize Contraction of the levator scapulae can correct this flaw in the synergy

In the illustrative examples given above, the synergies and neutralizations were worked out theoretically from a knowledge of the actions of various muscles A more practical situation occurs when a given exercise is considered, and the starting point is a knowledge of what action occurs By analysis the probable contractions of various muscles necessary for performing the exercise can be determined

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LABORATORY EXERCISES

1 Identify the movements of the shoulder girdle in the various phases of the basketball chest shot pullups pushups shot put

2 Analyze the value of various swimming stokes in the treatment of abducted shoulders

3 Measure the distance from the spine to the vertebral border of the scapulae of a number of subjects Determine whether the difference results from variations in body type or from functional factors

4 In general should inward or outward rotation of the arms be specified in corrective exercises? Why?

5 Is it possible to eliminate special corrective exercises and substitute sports competition as a means of correcting faulty posture or to prevent poor posture? State the basis by which you justify your answer

6 What action results from simultaneous contraction of parts 1 2 3 and 4 of the trapezius and the rhomboids? In this action, what actions of what muscles

TABLE 7 —Shoulder Girdle Muscles and Their Actions

	Eleva tion	*Depres sion*	*Abduc tion*	*Addu tion*	*Upward Rotation*	*Downward Rotation*
Subclavius		P M *				
Pectoralis minor		P M	P M			P M
Serratus anterior			P M		P M	
Trapezius I	P M					
Trapezius II	P M			Asst **	P M	
Trapezius III				P M		
Trapezius IV		P M		Asst	P M	
Levator	P M					
Rhomboid	P M			P M		P M

* P M = Prime Mover
** Asst = Assistant Mover

are mutually neutralized? Can two muscles (or parts of two muscles) work co operatively and antagonistically at the same time?

7 List the muscles covered in this chapter Describe the best progressive re sistance exercise to strengthen and hypertrophy each one

8 List the joint actions covered in this chapter and describe the best joint mobil- ization exercise for each one

9 Pick out one muscle or one group of muscles Describe an exercise in which the muscle contracts eccentrically and one in which it contracts concentrically

Chapter 10

Movements of the Shoulder Joint

THE shoulder joint, formed by the articulation of the humerus with the scapula, is the most freely movable of the ball and socket joints. The shallow glenoid fossa is deepened by a cup of cartilage, the *glenoid labrum*, attached firmly to the inner surface of the fossa, and the head of the humerus fits into the cup. The joint is surrounded by the usual *capsular ligament*, which is reinforced on the front side by a strong band of fibers connecting the humerus with the coracoid and called the *coracohumeral ligament*. Tendons of the subscapularis, the supraspinatus, the infraspinatus, the long head of the biceps and the long head of the triceps have an intimate relation to the capsule and add materially to its strength. The capsule is so loose that it permits the head of the humerus to be drawn out of the socket about one inch, but the tendency of the weight of the arm to pull it far out is resisted by the tone of the muscles. *The joint is protected by the acromion, which projects over it, by the coracoid* in front, and by the *coracoacromial, coraco humeral, transverse humeral,* and *gleno humeral ligaments* (Figs. 67 and 78.)

Starting from the resting position at the side of the body, movement of the arm away from the body in any direction may be called *elevation*. This term is ambiguous, therefore separate terms are given to elevations in different directions, and other terms apply to the corresponding depressions. From anatomical position, a forward elevation of the arm is called *flexion*; the return movement is *extension*. Backward elevation, which is a continuation of extension, is called *hyperextension*. *Abduction* is sideward elevation of the arm; *adduction* is the return movement. The extreme terminal position for abduction is the same as that for flexion, although it should be noted that an upward rotation of the shoulder girdle must be added to the shoulder joint movements in order to achieve this vertical position. It is possible to elevate the arm in diagonal planes between abduction and flexion and between abduction and hyperextension, but there is no standard terminology for these diagonal movements.

Inward rotation is the turning of the humerus around its long axis so that

its anterior aspect moves medially *Outward rotation* is the opposite, with the anterior aspect moving laterally When the arm is in other than the anatomical position a beginning student may find it difficult to determine whether rotation is inward or outward It is helpful to look along the long axis of the right arm toward the elbow—then, any counter clockwise rotation is inward, and any clockwise rotation is outward

If the arm is flexed to the horizontal it may then be moved horizontally backward This movement is called *horizontal extension abduction* (which may be abbreviated to either *horizontal extension* or *horizontal abduction*) The opposite of this movement a movement of the arm horizontally forward, is called *horizontal flexion adduction* (which may be abbreviated to either *horizontal flexion* or *horizontal adduction* Although unwieldy, these terms are most helpful in describing shoulder joint movements The beginning student

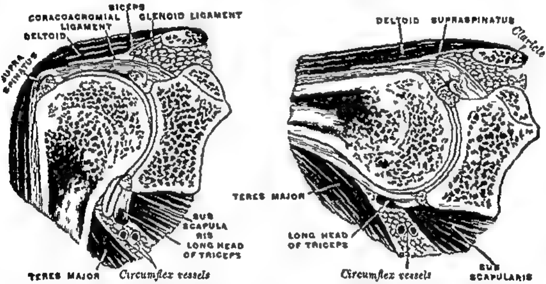

FIG 78—Vertical section through the right shoulder joint, seen from the front showing how sideward elevation of the arm is limited to 90 degrees (*Gray s Anatomy*)

should not be confused when these terms are applied to shoulder joint movements when the body is in the supine position or some other nonerect position They are still called horizontal movements, because terms are always defined with reference to erect anatomical position

Another possible source of confusion to the beginner is the failure to distinguish elbow or forearm movements from shoulder joint movements Shoulder joint rotation is often confused with forearm pronation and supination

Circumduction is not a pure movement like the aforementioned but is a combination of movements causing the elbow to describe a circle

Movements of the shoulder joint are produced by eleven muscles Two of these (the biceps and triceps) are primarily designed to act on the elbow joint, but they also cross the shoulder joint and are therefore known as two joint muscles The long and short heads of the biceps act as two different muscles

	Two Joint Muscles	*Large Muscles*	*Small Associates*	*Rotators of Humerus*
Above	Biceps (long head)	Deltoid	Supraspinatus	Infraspinatus
Front	Biceps (short head)	Pectoralis major	Coracobrachialis	Subscapularis
Rear	Triceps (long head)	Latissimus dorsi	Terres major	Teres minor

at the shoulder joint Of the three heads of the triceps only the long head acts at the shoulder The structure and function of the biceps and triceps will be discussed in Chapter 11 pp 183–188

DELTOID

This is a triangular muscle located on the shoulder, with one angle pointing down the arm and the other two bent around the shoulder to front and rear (Figures 70 79 and 80) It is proportionately far larger in man than in primitive mammalian forms [1]

Origin Along a curved line following the outer third of the anterior border of the clavicle the top of the acromion and the posterior border of the scapular spine

Insertion A rough spot on the outer surface of the humerus just above its middle

Innervation The axillary nerve from the brachial plexus The fibers are from the fifth and sixth cervical nerves

Structure In three parts—anterior middle and posterior The anterior and posterior portions are simple penniform while the middle is multipennate The tendon of insertion divides near the humerus into five strands the outer two, placed anteriorly and posteriorly receive the fibers of the front and rear portions of the muscle which arise directly from the bones above the middle has four tendons of origin passing down from the acromion and the three tendons of insertion passing up from below alternate between them the muscular fibers of the middle portion pass diagonally across between the seven tendons The result of the arrangement is that the middle part has more power and less extent of contraction than do the other two parts

Action Functionally the three parts of the deltoid should be considered as separate muscles

The *anterior portion* is a prime mover for flexion and horizontal flexion and an assistant mover for inward rotation and abduction above 60 degrees

The middle portion is a prime mover for abduction Its anterior fibers normally function as assistors to the anterior deltoid and its posterior fibers serve a similar function with the posterior deltoid

The posterior portion is a prime mover for horizontal extension and an assistant mover for extension adduction, and outward rotation [2]

This muscle is relatively ineffective for abduction when the arm is at an angle of less than 60 degrees and displays its greatest activity between 90 and 180 degrees When the arm is hanging at the side contraction of the deltoid tends to pull the humerus upward in the direction of its long axis This tendency is offset by the downward pull of the short rotators (subscapularis infraspinatus and teres minor) With the deltoid thus prevented from dissipat

ing its force in vertical movement, the combined action of the two groups of muscles tends to produce downward rotation of the head of the humerus and upward rotation of the shaft of the humerus [1] This is technically described as a force couple [2]

When the deltoid is electrically stimulated in isolation it does not lift the arm as high as the shoulder joint would permit because the scapula, being

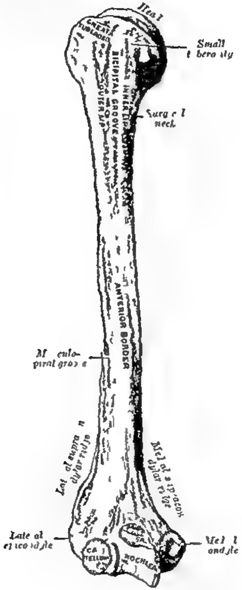

FIG 79 —The right humerus front view

somewhat free to move is rotated downward by the pull of the deltoid and the weight of the arm bringing the lower angle back well toward the spinal column depressing the acromion and making the posterior edge of the scapula stand out from the chest wall This downward rotation of the scapula gives the appearance of only a partial movement in the shoulder joint even when it has been performed to its full extent precisely as in attempts to raise the arm by those whose trapezius and serratus are destroyed In normal move-

ments involving the raising of the arm above the head the scapula rotates upward instead of downward greatly increasing the range of movement of the arm

Loss of one or more of the three portions of the deltoid interferes so seriously with all movements involving elevation of the arm that subjects with this defect have much difficulty in feeding and dressing themselves Loss of the posterior deltoid makes it impossible to put the hand behind the body at the waistline, if it is the front part the subject cannot bring his hand up to his face or put on his hat without bending the head far forward, if it is either the front or middle portion the arm cannot be lifted above the shoulder level in any direction When it is paralyzed the supraspinatus and other elevators may be hypertrophied to take its place as an abductor, although the force of the movement will be greatly reduced [3]

Fig 80 —The deltoid in action

The anterior deltoid hardens and swells out in all exercises in which the arm is raised or swung forward against a resistance the middle deltoid does the same when the movement is sideward the posterior part when it is backward The position of the arms in Figure 75 brings all three portions into action providing the subject holds his elbows well back All positions above the horizontal bring both anterior and middle portions into action It is easy to notice that a wider group of fibers contract in lifting a heavy weight than in lifting a light one also that both front and middle portions come into action before the shoulder level is reached if the load is heavy It is also easily seen that with quick arm elevation the deltoid contracts suddenly and then relaxes, leaving the momentum of the arm to finish the movement

SUPRASPINATUS

A small but relatively powerful muscle filling the supraspinous fossa and covered by the second part of the trapezius (Figs 71 and 213)

Origin The inner two thirds of the supraspinous fossa

Insertion The top of the greater tuberosity of the humerus

Innervation A branch of the suprascapular nerve from the brachial plexus The fibers come from the fifth cervical nerve

Structure Penniform the fibers arising directly from the bone and joining the tendon of insertion obliquely as it passes through the center of the muscle, much as the seeds of a pine cone join their stem

Action The supraspinatus pulls on the humerus with a short power arm and at a large angle since it joins the humerus above the axis while the load is below it it uses the humerus as a lever of the first class Since the power arm is the line from the insertion to the axis it is plain that the power and weight arms are not in a straight line but the lever is bent sharply at the axis This of course has no effect on the action of the muscle or its lever except to give it a favorable angle of pull

Isolated action of the supraspinatus which can be brought about by stimulating its nerve raises the arm diagonally outward, but the direction is not fixed and the arm may be moved forward or backward by the observer while the muscle is in contraction without hurting the subject It is powerful enough to lift the arm to its full height, even when the deltoid is lost but it is soon fatigued when so much work is put upon it It pulls the head of the humerus directly into the socket and so prevents the upward displacement which the pull of the deltoid tends to produce It is for this reason that persons who have lost the supraspinatus cannot do much work involving elevation of the arm

When the arm is near the side, the contraction of the deltoid is relatively ineffective and the movement of the supraspinatus is important in raising the arm laterally Some anatomists are of the opinion that the supraspinatus accomplishes the first 15 degrees of abduction of the arm If the muscle has been injured there may be a tendency for the head of the humerus to slip downward in abduction movements [3, 4]

Covered by a muscle that usually contracts at the same time, the supraspinatus is not easy to study

PECTORALIS MAJOR

A large fan shaped muscle lying immediately beneath the skin over the front of the chest The pectoral muscles originally comprised a single mass of which the pectoralis major was the superficial layer and the minor the deeper layer [1] Occasionally a pectoralis minimus extending from the first rib cartilage to the coracoid process may be found

Origin The inner two thirds of the anterior border of the clavicle the whole length of the sternum and the cartilages of the first six ribs near their junction with the sternum

Insertion By a flat tendon about 3 inches wide into the ridge that forms the outer border of the bicipital groove of the humerus extending from just below the tuberosities nearly down to the insertion of the deltoid (Fig 213)

Innervation Both the medial and lateral *anterior thoracic* nerves coming

ments involving the raising of the arm above the head, the scapula rotates upward instead of downward, greatly increasing the range of movement of the arm

Loss of one or more of the three portions of the deltoid interferes so seriously with all movements involving elevation of the arm that subjects with this defect have much difficulty in feeding and dressing themselves Loss of the posterior deltoid makes it impossible to put the hand behind the body at the waistline if it is the front part the subject cannot bring his hand up to his face or put on his hat without bending the head far forward, if it is either the front or middle portion the arm cannot be lifted above the shoulder level in any direction When it is paralyzed the supraspinatus and other elevators may be hypertrophied to take its place as an abductor, although the force of the movement will be greatly reduced [3]

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tion Both parts act strongly in horizontal flexion, and are assistant movers for inward rotation

In a study of amputees, Inman and Ralston[5] found that this muscle could exert a force of 1 63 kg per sq cm of cross section

Loss of the pectoralis major disables one much less than loss of the anterior deltoid, except in movements where great force is required When the deltoid is intact the subject can raise his hand to any position in front of the trunk, fold his arms place the hand on the opposite shoulder, etc , even if the pectoralis major is lacking The force of gravitation enables him also to lower the arm to or through any position with the aid of the deltoid but the power in forward and downward movements of the arm is lacking unless the pectoralis can help A study by Jokl[6] of the incidence of the congenital absence of different muscles among athletes has revealed that the pectoralis is by far the one most commonly affected

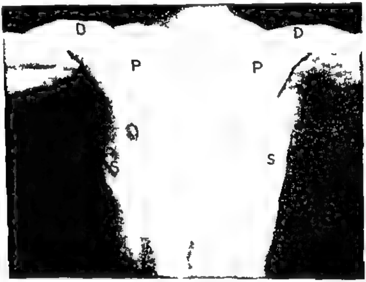

FIG 82 —The pectoralis major in action *P* pectoral *D* deltoid *S* serratus magnus

Beevor[7] has described an excellent way to begin the study of the pectoralis major on the living body First have the subject hold his arms forward a little below the horizontal and with elbows extended press his palms strongly together this brings the whole muscle into vigorous action and the two parts can be seen and felt plainly the tendon standing out in strong relief near the arm Now while the subject is doing this let the observer press down on the extended arms and have the subject resist the pressure this instantly causes relaxation of the lower half while the upper half springs out in still stronger action if the observer lifts against the arms and the subject resists, the upper half relaxes and the lower half acts Let the observer try to move the subject s arms alternately up and down while the subject tries to keep them still and notice the rapid change of action by watching the tendon near the arm Observe that both parts of the muscle contract in all exercises where there is horizontal flexion of the arms that the upper part works alone in flexion and that the lower part acts alone in extension Notice how plainly the upper half shows action in lifting with arms forward, as when a waiter carries a heavy tray

from the brachial plexus Fibers come from the fifth cervical to the first thoracic nerves

Structure The fibers arise directly from the bone and converge to join the tendon of insertion Near its insertion it is twisted through 180 degrees, the lower part passing beneath to be inserted near the head of the humerus while

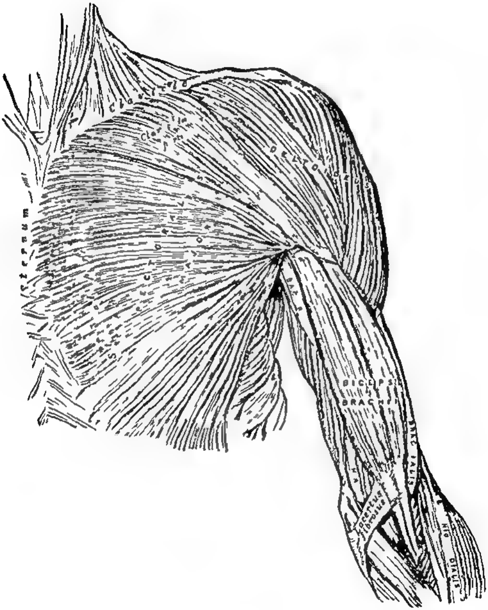

FIG 81 —Superficial muscles of the chest and front of the arm (*Gray s Anatomy*)

the fibers from the clavicle pass across them on the outside and join the humerus lower down (Fig 81)

Action The clavicular portion of the pectoralis major is a prime mover for flexion and an assistant mover for abduction after the arm has been abducted to horizontal The sternal portion is a prime mover for extension and adduc

rotate it inward to the neutral point, when the arm is in a position of inward rotation this muscle will rotate it outward to the neutral point

LATISSIMUS DORSI

A very broad muscle, as its name indicates, situated on the lower half of the back and lying immediately beneath the skin except for a small space, where it is covered by the lower trapezius (Fig 68)

Origin The spinous processes of the six lower dorsal and all the lumbar vertebræ, the back of the sacrum, the crest of the ilium, and the lower three ribs

Fig 84—The latissimus in action The subject is depressing his arms against resistance Notice the narrow upper end of the latissimus just below the arm and trace its upper and lower margins as it widens out *L* is near its center, *D* deltoid *T* long head of the triceps

Insertion The bottom of the bicipital groove of the humerus by a flat tendon attached parallel to the upper three fourths of the insertion of the pectoralis major (Fig 213)

Innervation The thoracodorsal nerve from the brachial plexus The fibers come from the sixth seventh and eighth cervical nerves

Structure The fibers converge from their wide origin much like the pectoralis major and like the latter its flat tendon is twisted so that the upper fibers go to the lower insertion and *vice versa* The muscle is joined to the lower vertebræ and the sacrum by a sheet of fibrous tissue called the *lumbar fascia* which also gives attachment to several other muscles

CORACOBRACHIALIS

A small muscle named from its attachments and located deep beneath the deltoid and pectoralis major on the front and inner side of the arm (Fig 83)

Origin The coracoid process of the scapula

Insertion Inner surface of the humerus, opposite the deltoid

Innervation Musculocutaneous nerve with the fibers coming from the sixth and seventh cervical nerves

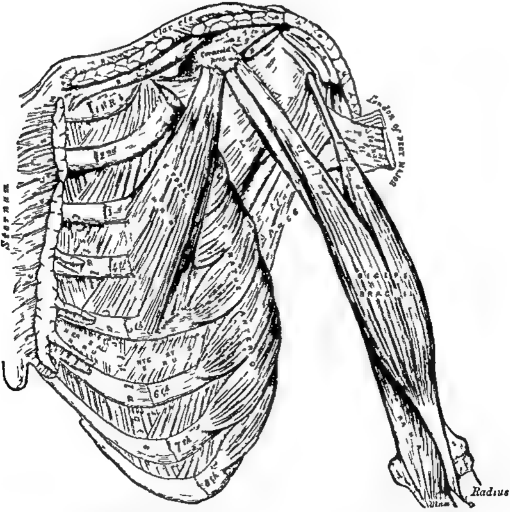

Fig 83 —Deep muscles of the chest and front of the arm with the boundaries of the axilla (*Gray s Anatomy*)

Structure The fibers arise from a short tendon and are inserted directly into the humerus Attachment to the tendon is penniform

Action This muscle is a prime mover for shoulder joint horizontal flexion and an assistant for flexion Because of its small size it cannot act as an effective substitute in flexion if the prime movers are paralyzed It stabilizes the shoulder joint tending to prevent downward displacement of the humerus When the arm is in a position of outward rotation the coracobrachialis will

Innervation The nerve supply of the infraspinatus is from the suprascapular nerve from the brachial plexus with its fibers coming from the fifth and sixth cervical nerves The teres minor is innervated by the axillary nerve with its fibers coming from the fifth cervical nerve

Structure Longitudinal converging fibers

Action The infraspinatus and teres minor are prime movers for outward rotation and horizontal extension of the shoulder joint An additional function not traditionally listed is their important participation in the force couple for abduction and flexion, as noted in the discussion of deltoid actions

SUBSCAPULARIS

Named from its position on the inner surface of the scapula, next to the chest wall (Figs 73 and 74) In primitive forms it is the largest muscle of the scapulo humeral group [1]

Origin The whole interior surface of the scapula (next to the ribs) except a small space near the joint (Fig 83)

Insertion The lesser tuberosity of the humerus (Fig 79)

Structure A multipennate muscle

Action The subscapularis forms a functional group with the infraspinatus and teres minor in the force couple for abduction and flexion, as noted in the discussion of deltoid actions It acts as a prime mover for inward rotation of the humerus, being antagonistic to the infraspinatus and teres minor in this respect

FUNDAMENTAL MOVEMENTS OF SHOULDER JOINT AND SHOULDER GIRDLE

Much of the preceding material on the movements of the shoulder girdle and the shoulder joint has dealt with individual bones, joints and muscles The analytical study of individual components, whether they be anatomical parts or phases of a movement is necessary for adequate comprehension of the pattern of which they are a part However as was stated in Chapter 3, a muscle seldom if ever acts alone From the practical standpoint the kinesiologist is usually interested primarily in the total movement which is the resultant of these individual actions The following paragraphs will emphasize certain important relationships resulting from the interaction of the individual muscles comprising the shoulder girdle and the shoulder joint

In nearly every arm movement there is an associated movement in the shoulder girdle and when the arm is held in a static position there must be a stabilization of the shoulder girdle in order to support it In most natural movements, there is a consistent and predictable pattern of shoulder girdle movement that accompanies any given movement of the shoulder joint This pattern can be altered by conscious attention to the process but this is not usually done in the activities of work sport and daily life

Elevation of the Arm Both flexion and abduction of the arm are accompanied by upward rotation of the shoulder girdle During the first 30 to 60 degrees of arm elevation the scapula may remain stationary or it may perform upward rotation in a pattern which depends upon the nature of the starting position the speed of movement the amount and direction of resistances and other variable aspects of the situation After abduction has taken place

Action The latissimus is a prime mover for adduction extension and hyperextension of the shoulder joint It assists in horizontal extension and inward rotation In rope climbing and similar activities it acts to draw the trunk up toward the humerus It is powerfully involved in swimming and rowing

Loss of the latissimus results in a forward displacement of the shoulder, due to the pull of the pectoral muscles, major and minor It noticeably weakens all downward movements of the arm When both the latissimus and pectoralis major are lost the shoulder is apt to be too high because of the lifting action of the trapezius and rhomboid

TERES MAJOR

A small round muscle lying along the axillary border of the scapula named larger round in comparison with the teres minor or smaller round muscle (Figs 71 72 and 83)

Origin The external surface of the scapula at the lower end of its axillary border

Insertion The ridge that forms the inner border of the bicipital groove of the humerus, parallel to the middle half of the insertion of the pectoralis major (Fig 213)

Innervation The lower subscapular nerve from the brachial plexus Fibers come from the fifth and sixth cervical nerves

Structure Fibers arising directly from the scapula and inserted into the tendon in a penniform manner

Action In their penetrating studies of muscular function at the shoulder joint Inman Saunders and Abbott[1] found that the teres major was never active during abduction and flexion movements but that it contracted statically with tension proportional to the load on the arm whenever a stationary position was reached This surprising activity of the teres major was explained mechanically and verified in clinical experiences The concept is theoretically important in advanced kinesiology and of practical importance in surgical *muscle transplantations to compensate for paralysis*

Except for this special function of the teres major its actions on the arm appear to be the same as those of the latissimus dorsi and it has been called the latissimus dorsi s little helper [8] However, it is a prime mover rather than an assistant mover for inward rotation

Loss of the teres major does not interfere with depression of the arm to nearly the same degree as does loss of either the pectoralis major or latissimus

INFRASPINATUS AND TERES MINOR

These two muscles located on the back of the scapula have identical action and hence will be studied together (Fig 71) Morphologically the teres minor is a portion of the deltoid it is absent in primitive mammalians [1]

Origin Infraspinatus Medial two thirds of the infraspinatus fossa teres minor dorsal surface of the axillary border of the scapula

Insertion Infraspinatus on middle of greater tuberosity of the humerus teres minor on lower part of greater tuberosity and adjacent shaft of the humerus

Finally with the arm extremely abducted, notice that it cannot be rotated inward to any significant extent Many authors have commented upon the limited abduction *when the arm is not rotated outward*, several reasons have been advanced to account for it Some have suggested that ligaments are responsible for stopping the movement, and that outward rotation makes them slack so that abduction can be continued Most, however, think that the greater tuberosity of the humerus impinges upon the top of the glenoid fossa or upon soft tissues which are pinched between it and the top of the glenoid fossa X ray studies have shown that the bony parts remain distinctly separated making it very likely that the abduction is limited by the pinching of soft tissues between the humeral tuberosity and the glenoid This relation

FIG 85 —Depressors of the arm in action *P* pectoral *C* coracobrachialis *L* latissimus

ship is shown in Figure 78 p 165 As the humerus is rotated outward so is the greater tuberosity, and abduction can be continued until muscles and ligaments on the inferior aspect of the joint become tight

SHOULDER JOINT DISLOCATION

The arrangement of bones at the shoulder joint allows rather free movement in three planes as well as marked rotation of the humerus around its long axis Such freedom of motion occurs at the sacrifice of joint stability The ligaments and muscles rather than the bones must be primarily responsible for preventing dislocation When the ligaments become permanently elongated as a result of repeated dislocations even well developed muscles are inadequate to prevent frequent further dislocation

through 30 degrees, or after flexion has taken place through 60 degrees, the relationship of arm elevation to upward rotation of the scapula becomes remarkably consistent with 2 degrees of shoulder joint movement being associated with every 1 degree of scapular rotation Demonstration of this by Inman and his associates [1] who inserted pins into the bones of living subjects and employed x ray pictures has served to resolve the many conflicting opinions regarding the movements in question

Backward elevation of the arm (hyperextension) is seldom accompanied by upward rotation of the scapula, but is often accompanied by elevation of the shoulder girdle

Flexion of the shoulder joint normally involves an associated abduction of the shoulder girdle along with upward rotation especially if the movement is a reaching or pushing action The serratus anterior is of great importance in movements of reaching and pushing since it is the only muscle which can simultaneously abduct and upward rotate the shoulder girdle

Depression of the Arm Extension of the shoulder joint is usually accompanied by downward rotation and adduction of the shoulder girdle adduction alone usually involves only downward rotation If the resistance consists only of the weight of the upper extremity with or without the weight of an object held in the hand and if the trunk is in an upright position the movement is ordinarily performed by eccentric contraction of the upward rotators of the shoulder girdle and the elevators of the shoulder joint If other kinds of forces are present as in the case of pulling on a horizontal rope the shoulder girdle downward rotators and adductors and the shoulder joint extensors may have to contract concentrically In this latter example the latissimus dorsi will also contract and it has an indirect tendency to adduct and rotate the shoulder girdle downward as it extends the shoulder joint In forceful adduction of the shoulder joint against resistance, the latissimus is joined by the sternal portion of the pectoralis major in causing shoulder joint adduction along with downward rotation of the shoulder girdle and the tendencies of these muscles to cause anterior and posterior deviations of the arm and shoulder girdle are mutually neutralized (Fig 85) The contributions of the latissimus dorsi and the pectoralis major to shoulder girdle action are clearly demonstrated when doing dips (sometimes called pushups) on the parallel bars and when arising from a chair by pushing down upon its arms

Rotation of the Arm Inward rotation of the shoulder joint is ordinarily accompanied by shoulder girdle abduction outward rotation is ordinarily accompanied by shoulder girdle adduction These tendencies are most marked when rotation is carried to its extreme In devising corrective exercises for abducted shoulders these natural tendencies should be taken into consideration

Horizontal Arm Movements Horizontal flexion at the shoulder joint is usually accompanied by shoulder girdle abduction horizontal extension is usually accompanied by shoulder girdle adduction

The Range of Arm Abduction An interesting relationship between arm abduction and arm rotation can be demonstrated by the following exercise From standing position with arms hanging at the sides palms toward the thigh abduct the arm as far as possible without rotating it Then rotate the arm outward and notice how much further the abduction can be continued

9 Bilik S E Prevention of Superimposed Disabilities New York State J Med *59* 1625–1628, 1954

10 Morehouse Laurence E and Rasch Philip J *Scientific Basis of Athletic Training* Philadelphia W B Saunders Co 1958 pp 186–188

TABLE 8 —Shoulder Joint Muscles and Their Actions

	Flex	*Ext*	*Abd*	*Add*	*Inw Rot*	*Outw Rot*	*Hor Flex*	*Hor Ext*
1 Anterior Deltoid	P M		Asst		Asst		P M	
2 Middle Deltoid			P M					P M
3 Posterior Deltoid		Asst		Asst		Asst		P M
4 Supraspinatus			P M					
5 Pect Major clavicular	P M		Asst *		Asst		P M	
6 Pect Major sternal		P M		P M	Asst		P M	
7 Coracobrachialis	Asst			Asst *	Asst †	Asst †	P M	
8 Subscapularis				Asst *	P M		Asst	
9 Latissimus dorsi		P M		P M	Asst			Asst
10 Teres major		P M		P M	P M			Asst
11 Infraspinatus						P M		P M
12 Teres minor						P M		P M
13 Biceps long head			Asst					
14 Biceps short head	Asst			Asst	Asst		Asst	
15 Triceps long head		Asst		Asst				

* Indicated action takes place only when arm is above the horizontal
† Indicated action takes place only from a position of rotation to the neutral point

LABORATORY EXERCISES

1 Analyze (*a*) the up movement and (*b*) the down movement of *pullups* Name the shoulder girdle and shoulder joint actions specific muscles active and kind of contraction

2 Assume that a man in the supine position is pressing a barbell to arm s length (*a*) What shoulder joint muscles are involved? (*b*) What will be the difference in the effect upon them resulting from keeping the hands wide apart or bringing them close together?

The humerus can be displaced backward (subspinous dislocation) down ward (subglenoid dislocation), or forward (subcoracoid dislocation) The subcoracoid dislocation is most likely to become chronic and it usually occurs when the arm is abducted and rotated outward The joint capsule is loose relatively thin and without reinforcements at its antero inferior aspect

Muscular pulls on the humerus by the pectoralis major may sometimes be responsible for subcoracoid dislocation This happens relatively often in sports especially when the humerus is outward rotated so that the tendon of insertion of the pectoralis major is stretched Forceful overhand throwing quick forward downward striking at a resistant object, and blocking with the forearms in football lineplay are examples of activities which combine strong contractions of the pectoralis major with a position of anatomical vulner ability

Implications for Athletic Training Because the intricate musculature and comparatively loose construction of the shoulder joint make it an instrument possessing a great range of movement but comparatively little resistance to traumatic forces, it may be literally knocked apart in such a sport as football or twisted apart in such a sport as wrestling The study of injuries in athletics very clearly points up the necessity for a vigorous exercise schedule aimed at strengthening this part of the body as an integral part of the preseason con ditioning program preceding participation in physical contact sports

Following trauma, the shoulder joint is especially susceptible to freezing and every effort should be made to keep it mobilized, even though activity is accompanied by some discomfort Heat massage and exercise are useful in overcoming any tendency to ankylosing fibrosis [9] Once a shoulder joint has sustained severe damage it tends to become susceptible to recurrent dislo cation (trick shoulder) and a restrictive harness designed to prevent the athlete from raising his arm higher than 85 degrees may become a necessity if he is to continue to participate in his chosen activities [10]

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Chapter 11

Movements of Elbow and Radio-Ulnar Joints

FUNCTIONALLY there is a distinct separation of the elbow joint and the radio ulnar joints the former allowing flexion and extension of the radius and ulna with respect to the humerus and the latter allowing pronation and supination of the forearm

Elbow flexion and extension take place through a range of approximately 150 degrees, depending upon individual variations in anatomy and use of the joint Flexion is limited by contact of the soft tissues of the arm and forearm, extension is limited by contact of the olecranon process of the ulna with the humerus Either may be hindered by the tightness of ligaments and muscles on the opposite aspect of the joint Some individuals can hyperextend the elbow, thus allowing it to be locked when supporting the body weight on the upper limbs or when pushing Most women can hyperextend the elbow and this is sometimes taken as evidence of a skeletal sex difference However it should be noted that many gymnasts weight lifters and others who often perform complete forceful extensions can also hyperextend the joint

When the elbow is extended inward and outward rotation of the arm at the shoulder joint may accompany pronation and supination, respectively, thus greatly increasing the amount of forearm rotation allowed by pronation and supination alone The total combined range of the movement in the two joints may approach 270 degrees In kinesiological analysis and in muscle testing the rotary movements of the shoulder joint and of the radio ulnar joints should be carefully distinguished

The Elbow Joint The elbow is a double ginglymus or hinge joint whose articular surfaces are (1) the semilunar notch of the ulna against the trochlea of the humerus where most of the weight is borne and (2) the proximal surface of the head of the radius against the capitulum of the humerus A capsule and synovial membrane enclose both of these articular pairs and also the proximal articulation between radius and ulna Pinching of the fringes of the synovial membrane in the joint has been suggested as a cause of tennis elbow [1] Longitudinal thickenings of this capsule are designated as the *anterior, posterior radial collateral* and *ulnar collateral ligaments*

3 Make a list of the muscles covered in this chapter and describe progressive resistance exercises best calculated to strengthen and hypertrophy each one

4 Why is it efficient to have fusiform arrangement of the fibers in the anterior and posterior deltoids but penniform arrangement of the fibers in the middle deltoid?

5 The ancient Romans are said to have been particularly interested in the development of large deltoids What sports might they have found especially useful for this purpose? Give reasons for your answer

6 In hand to hand combat a soldier might desire to dislocate an opponent s shoulder How might he apply force for this purpose? And in what direction?

7 Analyze the different types of swimming strokes and evaluate the role of the latissimus dorsi in each one

8 Assume that a man is lying supine holding dumbbells in his hands He first stretches his arms to the side and repeatedly brings the dumbbells together (lateral raise) He then stretches his arms overhead and repeatedly raises them to the vertical position (pull over) Analyze these two exercises and determine the difference in the effect on the muscles which are involved Will the muscular actions be the same if he is lying on a low bench instead of on the floor?

9 Analyze the role of the pectoralis major in delivering a left hook

resistance from the hand is transferred primarily to the radius at the wrist joint It remains largely for the interosseous membrane to resist the resulting tendency of the radius and ulna to slide past each other longitudinally

The *distal radio ulnar joint* is a pivot joint between the (distal) head of the ulna and the ulnar notch of the radius Two small transverse ligaments the *volar radio ulnar* and the *dorsal radio ulnar*, protect the joint as does the ligamentous *articular disk* which connects radius and ulna while separating the distal end of the ulna from the carpal bones The distal radio ulnar joint has its own synovial cavity and thin capsule In pronation and supination the end of the radius glides around the head of the ulna and rotates on its long axis to keep its articular surface toward the articulating surface of the ulna

TRICEPS BRACHII

The triceps is on the posterior side of the upper arm, and, as its name implies has three separate places of origin (Figs 87, 211 212, 214)

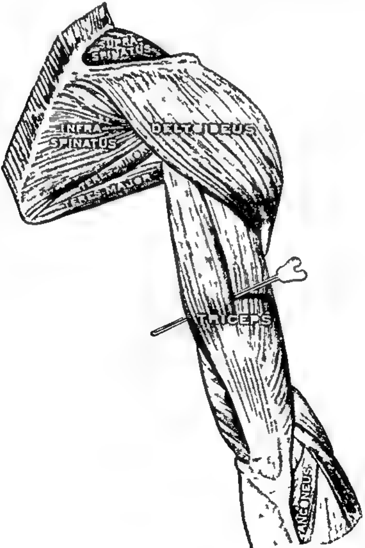

FIG 87 —Muscles on the back of shoulder and arm

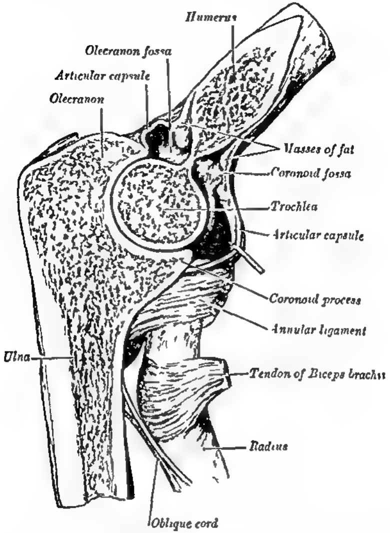

FIG 86 —Sagittal section through the left elbow joint (*Gray's Anatomy*)

The Radio ulnar Joint There are three distinct radio ulnar joints The *proximal radio ulnar joint* is a pivot joint between the head of the radius and the radial notch of the ulna It shares the synovial membrane and capsule of the elbow joint The annular ligament (Fig 86) encircles the head of the radius with both of its ends attaching to the ulna near the radial notch thus holding the head of the radius firmly in place During supination and pronation the radial head rotates axially within the annular ligament and the radial notch

The *middle radio ulnar joint* is classified as a syndesmosis The medial borders of the shafts of the radius and ulna are connected by a ligamentous sheet the *interosseous membrane* and the small *oblique cord* The fibers of the interosseous membrane run diagonally the attachment on the radius tending to be more proximal than that on the ulna Thus in addition to preventing undue separation of the bones it functions to transmit and to cushion the longitudinal forces of weight bearing In arm support positions the body weight is transferred from the humerus primarily to the ulna the force of

The leverage is short favoring speed rather than power The angle of pull is nearly 90 degrees through a large part of its movement the tendon passing over the lower end of the humerus as a pulley, the great number of short fibers in its structure together with its large angle of pull, gives the muscle great power as well as speed The origin of the middle head on the scapula enables that part to act on the shoulder joint as well as the elbow, a rubber band looped around the olecranon and held at the point of origin shows plainly that its pull is chiefly lengthwise of the humerus, lifting its head up into the glenoid cavity If the humerus is lifted the tension on the rubber band is increased, showing that it is able to aid in depressing the arm, but its angle of pull is here very small

Loss of the triceps destroys a person s ability to extend the elbow forcibly, but does not disable him for light tasks since the weight of the forearm will extend the elbow when there is no resistance making it possible to use the hands in any position when the movement requires little force

Contraction of the different parts of the triceps causes extension of the elbow Contraction of the long head alone assists in adduction, extension, and hyperextension of the humerus at the shoulder joint In a study of amputees, Inman and Ralston found that this muscle could exert a force of 1 31 kg per sq cm of cross section [2]

ANCONEUS

A small triangular muscle on the back of the arm (Fig 87) It appears to be a continuation of the triceps

Origin Posterior aspect of lateral epicondyle of the humerus

Insertion Lateral side of olecranon process and upper part of posterior aspect of the ulna

Innervation A branch of the radial nerve containing fibers from the seventh and eighth cervical nerves It will be noted that this innervation is identical with that of the triceps As a result the two muscles are usually disabled simultaneously in cases of neurological disease

Action Weak extension of the forearm Has been termed the triceps little helper [3]

BICEPS BRACHII

A prominent muscle on the front side of the upper arm with two separate places of origin (Fig 83)

Origin (1) The long head from the scapula at the top of the glenoid fossa the tendon passing over the head of the humerus and blending with the cap sular ligament of the shoulder joint (2) the short head from the coracoid

Insertion The bicipital tuberosity of the radius (Fig 89)

Innervation The musculocutaneous nerve from the brachial plexus Fibers come from the fifth and sixth cervical nerves

Structure The tendon of the long head is long and slender and lies in the bicipital groove of the humerus becoming muscular at the lower end of the groove The tendon of the inner head is shorter the muscular fibers of the two parts being of equal length The tendon of insertion is flattened as it joins the muscle and passes up as a septum between the two parts and receives the fibers in a penniform manner from both sides

Origin (1) The middle or long head, from the scapula just below the shoulder joint (2) the external head, from a space half an inch wide on the back of the humerus, extending from the middle of the shaft up to the greater tuberosity (3) the internal head from the lower part of the back of the humerus over a wide space extending nearly two thirds of the length of the bone

Insertion The end of the olecranon process of the ulna

Innervation The radial nerve from the brachial plexus with fibers from the seventh and eighth cervical nerves

Structure The long head has a short tendon of origin the fibers of the other two parts arise directly from the humerus The tendon of insertion

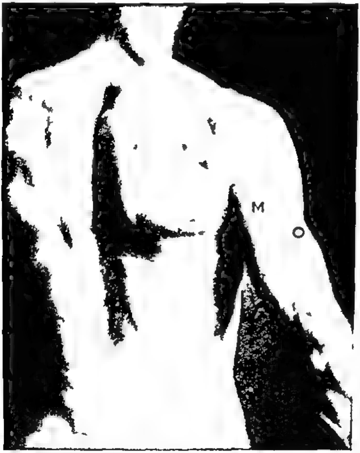

Fig 88 —The triceps in action *O* outer portion *M*, middle portion *I* inner portion

is flat and as it leaves the ulna it broadens into a thin sheet that extends far up the external surface of the muscle and the muscular fibers attach obliquely to its deeper surface The long head passes up between the teres major lying in front and the teres minor behind it

Action The olecranon process of the ulna extends past the elbow joint and the triceps is inserted into the end of it making of the ulna a lever of the first class Since the triceps pulls up on the olecranon it will evidently move the main part of the lever down and thus extend the elbow joint

With the forearm extended, supination does not produce any evidence of biceps potentials if rotation of the arm at the shoulder is prevented unless supination is firmly resisted[5 6]

Loss of the biceps does not necessarily result in inability to flex the elbow, since there are other muscles able to perform this movement Those who

FIG 91 —The arm of John McWilliams These amazingly hypertrophied muscles have a girth of 21½ inches and are believed to constitute the largest muscular arm on record (McWilliams)

retain the use of the other flexors but lack the biceps can do light work readily, but when they try to lift heavy objects the weight pulls the head of the humerus down out of its socket causing pain and quick fatigue When all the flexors are lost the use of the arm is practically abolished, as the subject cannot lift the hand to the face nor touch the body with the hand above the middle of the thigh

Action The biceps is in a position to act on three joints shoulder elbow and radio ulnar (Figs 89 90 91) At the shoulder joint, contraction of the long head of the biceps stabilizes the articulation and assists slightly with abduction Contraction of the short head assists with flexion abduction inward rotation and horizontal flexion Inman and Ralston found that the biceps can exert a force of 2 38 kg per sq cm of cross section [2] Both parts act to flex the elbow, the power arm being somewhat over an inch in length

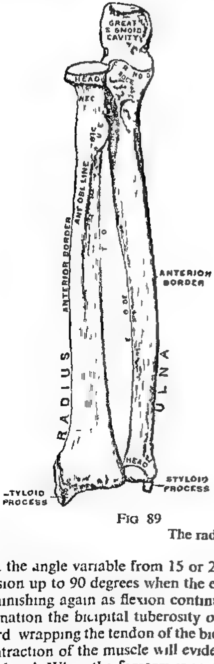

FIG 89

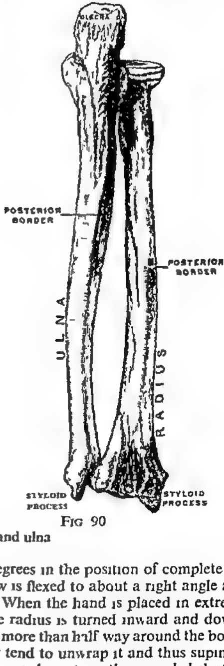

FIG 90

The radius and ulna

and the angle variable from 15 or 20 degrees in the position of complete ex tension up to 90 degrees when the elbow is flexed to about a right angle and diminishing again as flexion continues When the hand is placed in extreme pronation the bicipital tuberosity of the radius is turned inward and down ward wrapping the tendon of the biceps more than half way around the bone contraction of the muscle will evidently tend to unwrap it and thus supinate the hand When the forearm is in a pronated position the recorded electro myographic potentials from the biceps are lower than when the arm is in the supinated position [4]

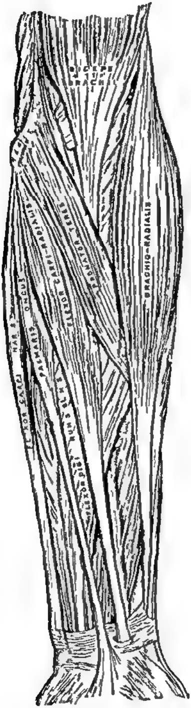

FIG 92 —Front of the left forearm superficial muscles (*Gray s Anatomy*)

forearms tend to assume a neutral position when a gymnast performs pullups on the rings

BRACHIALIS

Literally translated muscle of the upper arm It is located between the biceps and the humerus near the elbow (Fig 87)

Because the biceps acts as an important prime mover for both elbow flexion and forearm supination, a classic example of helping synergy arises when strong supination without elbow flexion is desired, as in driving a screw with a screwdriver or in turning a resistant doorknob In these tasks, the biceps is needed as a supinator but its simultaneous tendency to produce elbow flexion would cause the hand to be removed from the site of the work if flexion actually occurred The problem is solved by simultaneous contraction of the triceps, which as an elbow extensor effectively neutralizes the flexion tendency of the biceps while allowing its supinatory action to take place unhindered An easy classroom demonstration of this can be performed as follows With the elbow partially flexed, shake hands with a partner allowing him to turn his forearm to a position of extreme pronation With your left hand grasp his upper arm so that fingers are on his triceps and thumb is on his biceps Ask the partner to supinate his hand forcefully while you resist the motion Notice that his triceps springs into action at the same time as the biceps, in order to counteract the flexion tendency of the biceps as it supinates

There is sharp disagreement among electromyographers regarding the action of the biceps when the forearm is pronated It has been stated that the biceps plays little, if any, role in flexion at this time This has been explained by the assumption that in order to maintain the prone position against the biceps' tendency to supinate the forearm during contraction afferent impulses from the pronating muscles working through the central nervous system result in a negative feedback to the spinal centers controlling the biceps [6] However some students have contended that when the forearm is pronated the long head may contract while the short head may fail to show any signs of electrical activity [5] It is evident that much further study will be required to reconcile such discrepancies

BRACHIORADIALIS

Brachium is the Latin for the upper arm, hence the name indicates that the muscle is attached to the humerus and to the radius It is situated on the outer border of the forearm and gives rise to the rounded contour from the elbow to the base on the thumb (Fig 92)

Origin The upper two thirds of the lateral supracondyloid ridge of the humerus and from the lateral intermuscular septum

Insertion The lateral surface of the radius at the base of the styloid process

Innervation A branch of the radial nerve from the brachial plexus The fibers are from the fifth and sixth cervical nerves

Structure Arising directly from the humerus, the fibers join the lower tendon in a penniform manner

Action The position of the brachioradialis indicates it as a flexor of the elbow its leverage is long but its angle to pull very small computation shows that when both are taken into account it has better mechanical advantage than the biceps As a result flexion of the elbow is possible when a lesion of the musculocutaneous nerve results in paralysis of both the biceps and the brachialis If the median nerve is injured this muscle is the only one capable of producing pronation and its range is quite limited This muscle is an assistant for both pronation and supination tending to rotate the forearm from either extreme to the neutral position [6] This is one of the reasons why the

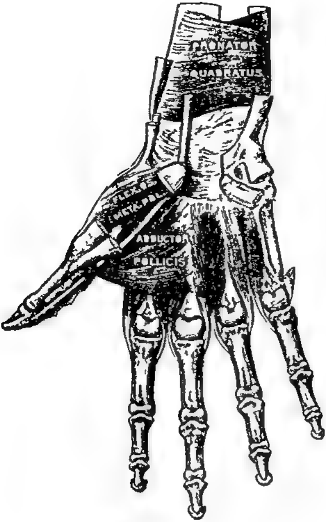

FIG 93 —Deep muscles near the wrist

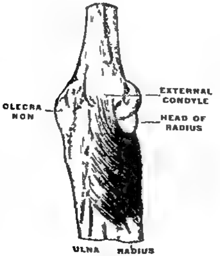

FIG 94 —The supinator

Origin Anterior surface of the lower half of the humerus and the inter muscular septa

Insertion Tuberosity of the ulna and the anterior surface of the coronoid process

Innervation Primarily by the musculocutaneous nerve from the brachial plexus with the fibers coming from the fifth and sixth cervical nerves A small branch of the radial nerve is usually present a branch of the median nerve may be

Structure The tendon of insertion flattens into a thin sheet and the muscular fibers arising from the humerus are attached obliquely to its deeper surface

Action Simple flexion of the elbow It is equally effective in the supine, mid or prone positions of the forearm since its line of pull does not change with rotation of the forearm The brachialis has been described as "the work horse among the flexor muscles of the elbow [5]

PRONATOR TERES

A small spindle shaped muscle lying obliquely across the elbow in front and partly covered by the brachioradialis (Fig 102)

Origin Two heads, one from the medial epicondyle of the humerus and the other from the coronoid process of the ulna

Insertion Outer surface of the radius near its center

Innervation A branch of the median nerve containing fibers from the sixth and seventh cervical nerves

Structure Fibers arising from short tendons join the tendon of insertion obliquely the latter lying beneath the muscle for half its length

Action Its primary action is pronation, if this is prevented the muscle acts to help flex the elbow In favorable subjects the pronator teres can be seen and felt in contraction without much difficulty In pure flexion it acts with the biceps its pronating action neutralizing some of the supinating action of the larger muscle In pure pronation against a resistance the triceps can be felt in mild contraction to neutralize the flexing action of the pronator teres just as it acts with the biceps in supination, but much less vigorously

PRONATOR QUADRATUS

A thin square sheet of parallel fibers lying deep on the front of the forearm near the wrist (Fig 93)

Origin Lower fourth of the front side of the ulna

Insertion Lower fourth of the front side of the radius

Innervation The volar interosseous nerve, which branches from the median nerve The fibers come from the eighth cervical and first thoracic nerve by way of the brachial plexus

Structure Parallel fibers attached directly to the bones

Action Pronation of the forearm working with the pronator teres

SUPINATOR

A broad muscle situated under the brachioradialis and the extensor muscles attached to the lateral epicondyle (Fig 94)

Origin Lateral epicondyle of the humerus supinator crest of the ulna ligaments between

much weight when it is held with the palms down (reverse curl) as he does when it is held with the palms up (curl)

Similar findings by Provins and Salter[10] have been explained on the following basis The difference in the strength of flexion at the various forearm positions must be due principally to changes in the length of and mechanical efficiency exerted by the biceps, brachialis, brachioradialis, and pronator teres Of these the brachialis is unaffected by rotation of the forearm As the forearm is rotated from supination to pronation, the length of the biceps becomes progressively longer, but the mechanical advantage decreases as the tendon is wrapped around the radius and the effective lever arm is reduced The brachioradialis has its greatest mechanical advantage at the midposition, but as its mechanical advantage increases in turning from supination or pronation, its length decreases In these two muscles these two factors probably cancel each out to a large extent The pronator teres, however is at its shortest length and its mechanical advantage is relatively poor in the pronated position The overall effect then, may be largely due to the changes in the pronator teres

Implications for Athletic Training Trauma to the elbow joint is relatively common in body contact sports such as football and wrestling in activities where the body is subject to impact forces, such as gymnastics and tumbling, and as a result of movements requiring sudden forcible hyperextension of the forearm, as in tennis serving[1] baseball pitching, and javelin throwing It is often immobilized or semi immobilized, during the acute period[11] Passive exercises and underwater exercises are often very useful aids to its remobilization

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Insertion Outer surface of the upper third of the radius

Innervation The radial nerve from the brachial plexus Fibers come from the sixth cervical nerve

Structure Mostly parallel fibers

Action Supination Unlike the biceps, it is not directly affected by the positions of the elbow and shoulder

FUNDAMENTAL MOVEMENTS

The fundamental movements of the elbow and the radio ulnar articulations are flexion, extension, pronation, and supination Almost every movement of the arm in such fundamental skills as pushing pulling throwing and striking involves not only the joints mentioned above but the shoulder and wrist as well While it is necessary to study their isolated movement at this time, this is rarely the case in concrete situations In the analysis of simple skillful motions executed by the arm and involving these joints it is necessary to consider their actions as they are related to the adjacent parts

Some baseball pitchers who depend on curves, inshoots and screwballs are troubled with recurring sore arms Such trauma is not surprising in view of the small size of most of the muscles of pronation and supination and in view of the tremendous limb velocity which is generated prior to the final snapping of the arm into a pronated or supinated position The straight fast ball pitcher often lasts longer in a game or in a career than the stuff pitcher

In the average person the flexors of the elbow are about one and one half times as effective as the extensors Steindler[7] gives the following figures for working capacity of the principal muscles

Flexors	
Biceps	4 58 kilogram meters
Brachialis	3 84
Brachioradialis	2 21
Pronator teres	1 39
Others (total)	2 42
Extensors	
Triceps	9 27
Anconeus	0 83

The effective strength which muscles can exert is to some extent controlled by the position of the bones In a group of adult males[8] the following mean isometric strength figures were recorded for forearm flexion in the positions of supination midposition and pronation

Position	*Mean*	*Standard Deviation*
Supination	43 2 pounds	8 4 pounds
Midposition	47 8	8 9
Pronation	27 5	4 4

Since it has been shown that strength measurements made by isometric tech niques are valid in expressing isotonic strength [9] it is evident that a man exercising his elbow flexors should expect to lift only about two thirds as

4 Note that inward and outward rotation of the shoulder joint are effective in adding to the forearm motions of pronation and supination, respectively when the elbow joint is fully extended In turning a knob, the total *range of motion* would be greater if the knob were at arm s length and the elbow joint were extended Greater turning *force* would be available however, if the elbow joint were flexed to 90 degrees so that the biceps tendon would be working at an optimal angle of insertion for exerting supinatory force Discuss the importance of such kinesiological considerations in designing machinery and instrument panels

5 Analyze the action of the muscles of the shoulder and arm in throwing a curve ball

6 Using a goniometer measure the range of movement of the elbow joint of as many subjects as possible Note the amount of flexion and extension possible for each subject Tabulate and determine the average value for both sexes Account for the difference

7 The motion of the elbow joint is pure flexion and extension however, the biceps a powerful flexor, also supinates which modifies its action

a Flexion With the arm horizontal and supported through its entire length to avoid the action of gravity on the long head of the biceps flex the forearm with the hand in (1) supination (2) pronation and (3) midposition Palpate to determine which muscles flex the forearm with no resistance and with moderate resistance

b Extension Stand facing a wall Place the palm of the hand, fingers pointing upward against the wall, and with the elbow at 90 degrees push against the wall Palpate to determine which muscles act to extend Next place the back of the hand against the wall with the elbows at 90 degrees and repeat the efforts to extend the elbow by pressing against the wall Palpate to determine which muscles contract Explain any differences

c Supination Grasp a doorknob thumb up with the elbow bent at 90 degrees Twist the doorknob to supinate the hand Palpate to determine the active muscles

TABLE 9 —Elbow and Radio Ulnar Articulation Muscles and Their Actions

Muscle	*Flexion*	*Extension*	*Pronation*	*Supination*
Biceps brachii	P M			P M
Brachialis	P M			
Brachioradialis	P M		Asst *	Asst *
Pronator teres	Asst		P M	
Pronator quadratus			P M	
Triceps brachii		P M		
Anconeus		Asst		
Supinator				P M
Flexor carpi radialis	Asst		Asst	
Flexor carpi ulnaris	Asst			
Palmaris longus	Asst			
Extensor carpi radialis longus		Asst		Asst
Extensor carpi radialis brevis		Asst		
Extensor carpi ulnaris		Asst		
Flexor digitorum sublimis	Asst			
Extensor digitorum communis		Asst		
Extensor digiti quinti proprius		Asst		
Extensor pollicis longus				Asst
Abductor pollicis longus				Asst

* To the neutral position

LABORATORY EXERCISES

1 Demonstrate the peculiar action of the radius with reference to the ulna in movements of pronation and supination List some common activities which would be virtually impossible if the forearm could not be pronated and supinated

2 Classify and analyze the bone muscle levers at the elbow Are they designed for producing speed or power?

3 In what positions should the elbow and shoulder joints be held in order to make possible the delivery of maximal supinatory force?

listinct joints permitting an unusual amount of freedom of movement of he hand

(1) The radiocarpal joint lies between the end of the radius and three of the first row of carpal bones the navicular, the lunate, and the trian gular Neither the ulna or pisiform bone participate the ulna being sepa rated from the carpal bones by an articular disk of fibro cartilage The three carpal bones slide across the head of the radius the direction depending upon the nature of the movement The radiocarpal joint is enclosed in a strong but loose capsule strengthened by four strong areas of ligamentous tissue joining the proximal edges of the carpal bones to the bones of the forearm These ligaments are the volar and dorsal radiocarpal ligaments and the radial and ulnar collateral ligaments The joint permits all classes of movement except rotation

(2) The midcarpal articulation is a gliding joint between the two rows of carpal bones It has its own synovial sac which often includes portions of the carpometacarpal joint The pisiform bone is joined to the triangular in a separate synovial sac The joint is supported by the volar ligaments which join the volar surface of the first row to the volar surface of the capitate The dorsal ligaments join the first and second rows and the ulnar and radial collateral ligaments join the navicular with the greater multangular and the triangular with the hamate They may be regarded as extensions of the corresponding ligaments of the radiocarpal joint The small amount of gliding possible in the joint permits some flexion and slight extension

The bones of each row also articulate between others of the same row by arthrodial joints and are joined to each other by strong ligaments The three bones of the first row are joined by volar, dorsal and interosseous ligaments The pisiform is not included but does have two volar ligaments one joining it to the hamate and the other joining it to the fifth metacarpal The second row has three dorsal and three volar ligaments joining the four bones as well as the usual interosseous ligaments

(3) The carpometacarpal joints are also arthrodial Each metacarpal is united by two strong dorsal ligaments to the adjacent carpal bones except the fifth which has only one The volar aspect has a somewhat similar arrange ment except that the third metacarpal is attached to the adjacent carpals by three ligaments Interosseous ligaments also strengthen the joint

Together the wrist joints permit abduction adduction circumduction, flexion and extension The free rotation of the shoulder and radio ulnar joints give the hand freedom to turn through 270 degrees Starting from the straight extended position the wrist can be flexed through from 60 to 90 degrees The first and fifth metacarpals can be flexed farther than those between making it possible to draw the two sides of the palm toward each other forming a cup shaped depression in the middle of the palm

The first carpo metacarpal joint (that of the thumb) is atypical It is a saddle joint with a strong but loose capsule permitting much more freedom of movement than do the other carpo metacarpal joints From anatomical posi tion, a lateral separation of the first metacarpal bone from the second is called *abduction of the thumb*, the return movement is called *adduction* (and when it is continued across the palm *hyperadduction*) A movement of the first metacarpal bone forward from anatomical position approximately in the antero posterior plane, is called *flexion of the thumb*, the return movement is

Chapter 12

Movements of the Wrist and Hand

THE hand includes twenty seven bones and over twenty joints, while its action involves the use of thirty three different muscles The larger muscles acting on the hand are located in the forearm and are connected with their insertions by long slender tendons These tendons are held within a small space at the wrist by a deep concavity on the anterior surface of the carpal bones and by a flat encircling band of connective tissue known as the annular ligament of the wrist There are several small muscles in the hand itself the largest group making up what is known as the thenar eminence on the thumb side of the palm and a smaller group forming the hypothenar eminence on the ulnar side

The twenty seven bones of the hand form three groups (1) the carpal bones, eight in number in two rows of four bones each (2) the five meta carpal bones numbered beginning at the thumb, and (3) the fourteen pha langes in three rows the proximal and terminal rows containing five each and the second row four the phalanx of the middle row being absent in the thumb (Figs 95 and 96) The carpal or wrist bones are very irregular in shape and are named as follows beginning on the thumb side

First row navicular lunate triangular and pisiform

Second row greater and lesser multangular capitate and hamate

Some of the older texts use the following nomenclature

First row scaphoid semilunar cuneiform and pisiform

Second row trapezium trapezoid os magnum and unciform Minor var iations of both of these lists are occasionally seen

The metacarpals are considerably larger and longer than any of the pha langes and the latter decrease in size toward the tips of the fingers The phalanges of the terminal row are small and pointed The thumb is separated from the first or index finger more widely than the other fingers are from one another and is turned on its axis so that flexion is somewhat toward the others rather than in the same plane Notice the rounded articular surfaces at the ends of the metacarpals and phalanges

The wrist, which connects the rest of the hand with the forearm, has three

The metacarpo phalangeal joints each have a capsule, one volar ligament, and two collateral ligaments The first metacarpo phalangeal joint (that of the thumb) is a hinge joint capable only of flexion and extension through about 90 degrees The second through fifth metacarpo phalangeal joints are condyloid, permitting movement in two planes First flexion and extension may occur through about 90 degrees, and, in addition hyperextension may

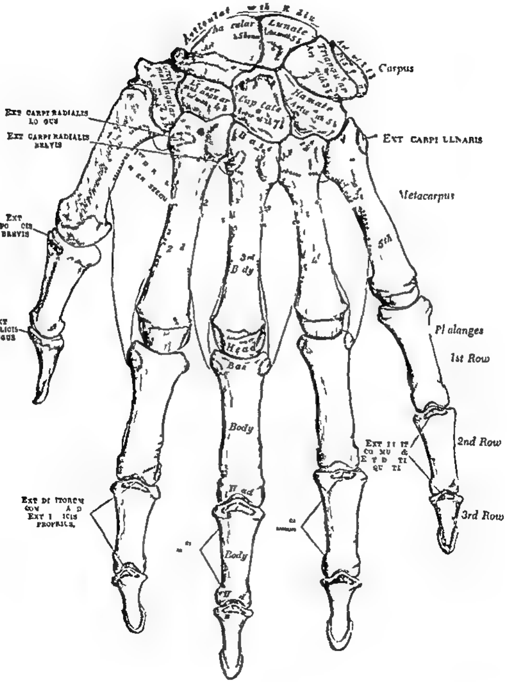

FIG 96 —Dorsal aspect of left hand (*Gray s Anatomy*)

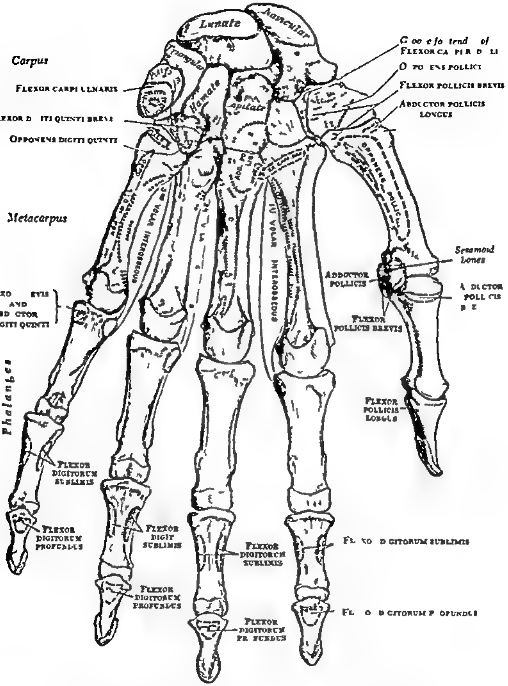

Fig 95 —Volar aspect of left hand (*Gray s Anatomy*)

extension In addition the first metacarpal bone may execute a peculiar partial circumduction and rotation which is called *opposition* because it brings the tip of the thumb around in position to face or oppose the fingertips The return movement from opposition is known as *reposition* *

* Some older textbooks interchange the definitions of abduction adduction with those for flexion-extension When consulting various texts the authors definitions should be checked

Action Tightens fascia of the palm Because of its small size it assists weekly in wrist flexion

FLEXOR CARPI ULNARIS

Located on the medial side of the forearm (Fig 97)

Origin The medial epicondyle of the humerus and medial margin of the olecranon and upper two thirds of the dorsal border of the ulna

Insertion The palmar surfaces of the pisiform and hamate bones and of the fifth metacarpal

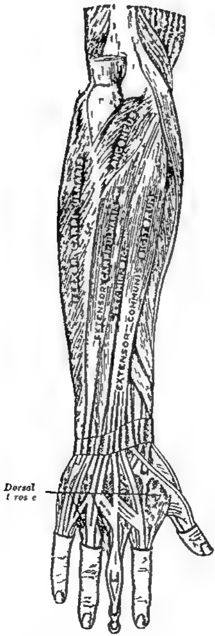

Fig 97 —Posterior surface of the forearm and hand

occur, varying from a few degrees to as much as 40 degrees in the second and fifth fingers Second, lateral movements (abduction and adduction) are possible The terminology for these lateral movements is variable, depending upon the textbook consulted In this text, the movements are defined consistently with the general scheme for naming abduction and adduction in other parts of the body Therefore, it is first assumed that the body is in anatomical position (erect, arms hanging at the sides palms turned forward) From this position, when any of the four fingers is moved laterally (*away from the midline of the whole body*), the movement is called abduction, and when any of the four fingers is moved medially (*toward the midline of the whole body*), the movement is called adduction It should be noted that some texts define abduction as a spreading of the fingers away from the middle finger and adduction as a closing of the fingers toward the middle finger, in which case some special terms, such as radial flexion and ulnar flexion must be introduced to name the movements of the middle finger Again, definitions must be checked in each individual textbook which is consulted

The inter phalangeal joints are capable only of flexion and extension, being hinge joints Each has a capsule reinforced by one volar and two collateral ligaments

MUSCLES ACTING ON THE WRIST JOINT

There are six principal muscles acting on the wrist joint grouped as follows

Flexor carpi radialis	Extensor carpi radialis longus
Flexor carpi ulnaris	Extensor carpi radialis brevis
Palmaris longus	Extensor carpi ulnaris

In addition the extrinsic muscles of the hand which cross the wrist may act as assistant movers for wrist motions

Abduction of the hand is produced by the combined action of the radial flexor and extensor while the ulnar flexor and extensor together adduct it

FLEXOR CARPI RADIALIS

This muscle lies on the upper half of the front of the forearm just beneath the skin half way from the brachioradialis to the ulnar side (Fig 92)

Origin The medial epicondyle of the humerus

Insertion The anterior surface of the base of the second metacarpal with a slip to the base of the third metacarpal

Innervation The median nerve with its fibers coming from the sixth and seventh cervical nerves by way of the brachial plexus

Action Flexion and abduction of the wrist

PALMARIS LONGUS

A slender muscle lying just on the medial side of the preceding It is absent in about 10 per cent of the individuals

Origin The medial epicondyle of the humerus

Insertion The annular ligament of the wrist and the palmar aponeurosis (Fig 92)

Innervation The median nerve with its fibers coming from the sixth and seventh cervical nerves by way of the brachial plexus

FLEXOR DIGITORUM SUBLIMIS

Situated just beneath the flexor carpi radialis and the palmaris longus on the anterior side of the forearm (Fig 92)

Origin The medial epicondyle of the humerus, the coronoid process of the ulna, and a long oblique line on the middle half of the anterior surface of the radius

Insertion By four tendons which separate after passing the wrist and go to the four fingers Opposite the first phalanx each tendon splits into two parts, which are inserted into the sides of the base of the second phalanx (Fig 99)

Innervation The median nerve from the brachial plexus Fibers come from the seventh and eighth cervical and the first thoracic nerves

Action Flexes the second and first phalanges, assists in wrist flexion

FLEXOR DIGITORUM PROFUNDUS

Located just beneath the flexor sublimis (Fig 98)

Origin The upper three fourths of the anterior and medial surfaces of the ulna

Insertion By four tendons which separate after passing the wrist and go to the four fingers Each tendon passes through the split in the corresponding flexor digitorum sublimis tendon and is inserted into the posterior surface of the base of the last phalanx (Fig 99)

Innervation The volar interosseous nerve the fibers of which come from the brachial plexus by way of the median and ulnar nerves Fibers are from the eighth cervical and first thoracic nerves

Action Flexes the third second and first phalanges assists in wrist flexion

Although the flexors sublimis and profundus each form a single muscular mass, the separate tendons to the fingers are moved by separate groups of muscle fibers, so that it is possible to flex the fingers separately The wide difference seen in the abilities of different persons to do this is due to differ ences in coordination resulting from various amounts and kinds of training and not from differences in the structure of the muscles

EXTENSOR DIGITORUM COMMUNIS

Situated on the middle of the dorsal surface of the forearm (Fig 97)

Origin The lateral epicondyle of the humerus

Insertion By four tendons which separate after passing the wrist and go to the four fingers Each tendon is attached by fibrous slips to the dorsum of the first phalanx and then divides into three parts the middle part is inserted into the posterior surface of the base of the second phalanx and the two collateral parts into the dorsal expansion of the finger extensor tendons

Innervation The radial nerve from the brachial plexus Fibers come from the sixth seventh and eighth cervical nerves

Action Contraction of the extensor digitorum communis extends the first phalanx and the wrist If the first phalanx is held flexed the muscle will extend the other phalanges but if the first phalanx or the wrist are allowed to extend its contraction has little effect on the last two phalanges This is partly due to the insertion of the tendons into three successive segments of

Innervation The ulnar nerve from the brachial plexus Fibers are from the eighth cervical and first thoracic nerves

Action Flexion and adduction of the wrist Electrical stimulation of the flexor carpi ulnaris does not adduct the hand but in voluntary adduction it contracts along with the extensor carpi ulnaris probably to prevent the hyperextension the latter would otherwise produce

By flexing the wrist strongly against a resistance, the tendons of the three flexor muscles can be easily felt The palmaris longus tendon should not be confused with the larger flexor digitorum sublimis tendon (Fig 92)

EXTENSOR CARPI RADIALIS LONGUS

This muscle is on the radial side of the upper forearm, just posterior to the brachioradialis (Fig 92)

Origin The lower third of the lateral supracondylar ridge of the humerus

Insertion The dorsal surface of the base of the second metacarpal

Innervation The radial nerve from the brachial plexus Fibers come from the sixth and seventh cervical nerves

Action Extension and abduction of the wrist joint

EXTENSOR CARPI RADIALIS BREVIS

Situated just beneath the preceding muscle

Origin The lateral epicondyle of the humerus

Insertion The dorsal surface of the base of the third metacarpal

Innervation The radial nerve from the brachial plexus Fibers come from the sixth and seventh cervical nerves

Action Extension and abduction of the wrist

EXTENSOR CARPI ULNARIS

Situated on the back and ulnar side of the forearm (Fig 97)

Origin The lateral epicondyle of the humerus and the middle third of the narrow ridge on the dorsal border of the ulna

Insertion The posterior surface of the base of the fifth metacarpal

Innervation The deep radial nerve from the brachial plexus Fibers are from sixth seventh, and eighth cervical nerves

Action Extension and adduction of the wrist

MUSCLES MOVING THE FINGERS

There are three muscles in the forearm that act on all four fingers at once, two of them flexors and one an extensor They are named—

Flexor digitorum sublimis
Flexor digitorum profundus
Extensor communis digitorum

meaning superficial and deep flexors and common extensor of the fingers Each of these muscles has four tendons going to the four fingers beginning at the lower fourth of the forearm and each tendon is acted upon by separate groups of muscle fibers making it possible to flex and extend the fingers separately as well as all at once

the finger and partly to leverage and slack, as explained in case of the flexors Since the extensor digitorum communis has the best leverage on the wrist strong extension of the fingers is impossible unless the wrist is prevented from hyperextending as the muscle contracts

EXTENSOR INDICIS PROPRIUS

A long thin muscle medial to and paralleling the extensor pollicus longus

Origin Dorsal surface of the lower half of the body of the ulna and the interosseous membrane

Insertion Into the ulnar side of the tendon of the index finger of the extensor digitorum communis, and into the dorsal expansion of the finger extensor tendons

Innervation The deep radial nerve of the brachial plexus Fibers arise from the sixth seventh and eighth cervical nerves

Action Extends and assists with adduction of the first phalanx of the index finger, assists with wrist extension Acting through the dorsal expansion it extends the second and third phalanges especially when the first phalanx is held in flexion

EXTENSOR DIGITI QUINTI PROPRIUS

A long thin muscle medial to and paralleling and often attached to the extensor digitorum communis

Origin Arises from the common tendon of the extensor digitorum communis

Insertion Into the tendon of the extensor digitorum communis at the first phalanx of the little finger and into the dorsal expansion of the finger extensor tendons

Innervation The deep radial nerve of the brachial plexus Fibers arise from the sixth seventh and eighth cervical nerves

Action Extends the first phalanx of the little finger, and assists with wrist extension Acting through the dorsal expansion it extends the second and third phalanges, especially when the first phalanx is held in flexion

MUSCLES IN THE HAND

There are three groups of small muscles placed in the hand itself that help to flex and extend the fingers and also to adduct and abduct them There are eleven of these muscles as follows

Four lumbricales
Four dorsal interossei
Three palmar interossei

In addition there are three muscles which act on the little finger alone their action contributing to some of the unusual features of the hand

The lumbricales are in the palm and the interossei lie between the metacarpal bones All eleven act to flex proximal phalanges and to extend middle and distal phalanges

THE LUMBRICALES

Four little spindle shaped muscles named from their resemblance to an earthworm (lumbricus) (Fig 99)

FIG 98 —Front of left forearm Deep muscles (*Gray s Anatomy*)

Innervation The first two lumbricales from the third and fourth digital branches of the median nerve, containing fibers from the sixth and seventh cervical nerves The third and fourth lumbricales from branches of the palmar branch of the ulnar nerve containing fibers from the eighth cervical nerve

Action The lumbricales flex and assist with abduction of the first phalanges, and they extend the second and third phalanges as prime movers when the first phalanx is held in extension

THE DORSAL INTEROSSEI

Four small muscles lying between the five metacarpal bones at the back of the hand

Origin Each from the two bones between which it lies

Insertion The base of the first phalanx and the dorsal expansion of the finger extensor tendons (Fig 100)

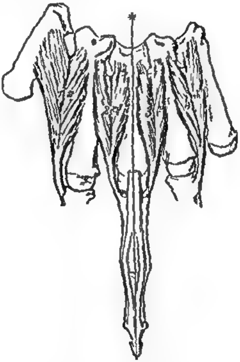

Fig 100 —Dorsal interossei of the left hand (*Gray s Anatomy*)

Innervation The palmar branch of the ulnar nerve with fibers coming from the eighth cervical and first thoracic nerves by way of the brachial plexus

Action The first and second abduct the index finger and middle fingers The third and fourth adduct the middle and ring fingers All assist in flexing the proximal phalanges of the index, middle, and ring fingers and assist in extending the middle and distal phalanges of the same fingers

THE PALMAR INTEROSSEI

Three small muscles in the palm on the central sides of the second, fourth, and fifth metacarpals

Origin Sides of the metacarpals except the first and third

Origin The tendons of the flexor profundus digitorum

Insertion The tendon of each muscle turns around the radial side of the metacarpal bone and is inserted into the dorsal expansion of the finger extensor tendons

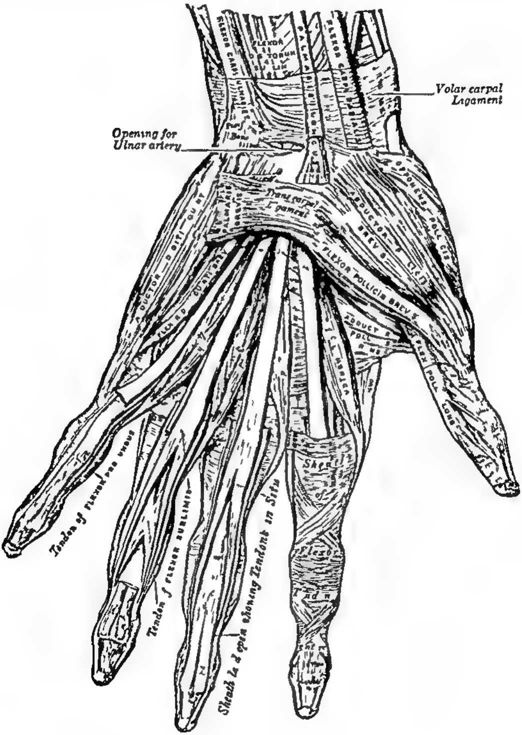

FIG 99 —The muscles of the left hand Palmar surface (*Gray s Anatomy*)

Origin The hamate bone and the contiguous parts of the transverse carpal ligament

Insertion The ulnar side of the first phalanx of the little finger

Innervation Branch of the ulnar nerve from the brachial plexus Fibers from the eighth cervical and first thoracic nerves

Action Flexes the proximal phalanx of the little finger

OPPONENS DIGITI QUINTI

A triangular muscle immediately beneath the preceding muscles

Origin Convex surface of the hamate bone and the contiguous portion of the transverse carpal ligament

Insertion The ulnar margin of the entire length of the metacarpal bone of the little finger

Innervation The ulnar nerve from the brachial plexus with fibers from the eighth cervical and first thoracic nerves

Action Slight flexion and rotation of the fifth metacarpal in cupping the hand (Fig 99)

MUSCLES MOVING THE THUMB

Of the eight muscles moving the thumb four are in the forearm and four in the thenar eminence Some of these muscles correspond to muscles that act on the fingers and it will help in understanding and remembering the new ones to keep such resemblances in mind

Three of the four muscles of this group that are located in the forearm are extensors of the thumb, one for each of its three segments

EXTENSOR POLLICIS LONGUS

The extensor pollicis longus lies on the back of the forearm next to the extensor indicis and like it may be considered to be a part of the extensor communis digitorum The tendon is shown in Figure 97 It forms the ulnar boundary of the anatomical snuff box

Origin Posterior surface of the middle third of the ulna and the interosseus membrane

Insertion The posterior surface of the base of the last phalanx of the thumb

Innervation The deep radial nerve with fibers from the sixth seventh and eighth cervical nerves by way of the brachial plexus

Action It extends the last phalanx of the thumb and then if the movement is continued it extends the other joints drawing the thumb into the plane of the rest of the hand May assist in extending the wrist

EXTENSOR POLLICIS BREVIS

This muscle lies deep beneath the extensor communis on the back of the forearm Its tendon forms the radial boundary of the anatomical snuff box

Origin Small spaces on the dorsal surfaces of both radius and ulnar near their middle

Insertion The posterior surface of the base of the first phalanx of the thumb

Innervation The deep radial nerve with fibers from the sixth and seventh cervical nerves by way of the brachial plexus

Insertion The base of the first phalanges of the index, ring and little fingers (Fig 101)

Innervation The palmar branch of the ulnar nerve with fibers coming from the eighth cervical and first thoracic nerves by way of the brachial plexus

Action The first palmar interosseous muscle adducts the first phalanx of the index finger The second and third interosseus muscles abduct the first phalanx of the ring and little fingers All three assist in flexing the proximal phalanges of the index ring and little fingers respectively and in extending the second and third phalanges of the same fingers

ABDUCTOR DIGITI QUINTI

Easily palpated on the ulnar border of the hand (Fig 99)

Origin Arises from the pisiform bone and from the tendon of the flexor carpi ulnaris

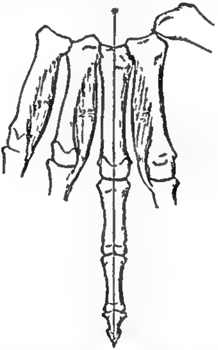

FIG 101 —Palmar interossei of the left hand (*Gray s Anatomy*)

Insertion Two slips one inserted into the ulnar side of the base of the first phalanx of the little finger the other into the ulnar border of the aponeurosis of the extensor digiti quinti brevis with connections from each to the dorsal expansion of the finger extensor tendons

Innervation The ulnar nerve from the brachial plexus with fibers from the eighth cervical nerve

Action In spite of its name this muscle adducts the little fingers It also assists in flexing its proximal phalanx

FLEXOR DIGITI QUINTI BREVIS

This small muscle lies just inside and alongside the previous muscle (Fig 99)

Insertion The anterior surface of the base of the last phalanx of the thumb

Innervation The volar interosseous nerve from the median Fibers come from the eighth cervical and first thoracic nerves

Action Flexes the second phalanx of the thumb Continued action flexes the first phalanx and flexes and adducts the metacarpal and wrist

FLEXOR POLLICIS BREVIS

This is the inner of the two short flexors (Fig 98)

Origin The lower part of the ridge of the greater multangular bone and the lower border of the transverse carpal ligament

Insertion Base of the first phalanx of the thumb on the radial side

Innervation The median nerve with fibers from the sixth and seventh cervical nerves

Action Flexion of the first phalanx flexion and adduction of the metacarpal of the thumb

OPPONENS POLLICIS

A small triangular muscle beneath the abductor pollicis brevis

Origin The greater multangular and transverse carpal ligament

Insertion The shaft of the metacarpal bone on its radial side

Innervation The median nerve with fibers from the sixth and seventh cervical nerves

Action Opposition which is a partial circumduction of the metacarpal of the thumb By its use the tip of the thumb can be made to meet the tips of the four fingers in turn (Fig 102)

ABDUCTOR POLLICIS BREVIS

This is the most superficial muscle of the lateral part of the thenar eminence (Fig 98)

Origin The tuberosity of the navicular and the ridge of the greater multangular bones Another slip originates from the transverse carpal ligament

Insertion The lateral surface of the base of the first phalanx of the thumb

Innervation The median nerve with fibers from the sixth and seventh cervical nerves

Action Flexion of the first metacarpal of the thumb

ADDUCTOR POLLICIS

This is the deepest of the thenar muscles (Figs 102 and 103)

Origin The oblique head arises from the capitate bone the bases of the second and third metacarpals and the intercarpal ligaments The transverse head arises from the lower two thirds of the volar surface of the third metacarpal bone

Insertion The medial surface of the base of the first phalanx of the thumb

Innervation The deep palmar branch of the ulnar nerve Fibers come from the eighth cervical and first thoracic nerves

Action Adduction and hyperadduction of the first metacarpal of the thumb If the thumb is in a position of flexion and hyperadduction it will extend the first metacarpal bringing it to the surface of the palm

Action Extends the first phalanx of the thumb and, by continued action, abducts the first metacarpal and the wrist

ABDUCTOR POLLICIS LONGUS

This, the last of the long extensors acts, as its name indicates on the metacarpal bone of the thumb It lies just below the supinator and is sometimes united with it

Origin A small space on the ulnar side of the radius near its middle the lateral part of the dorsal surface of the body of the ulna just below the insertion of the anconeus and the interosseous membrane

Insertion The radial side of the base of the first metacarpal

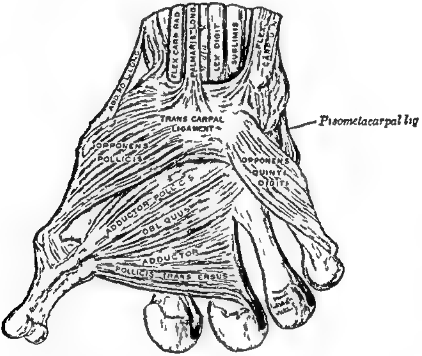

FIG 102 —The muscles of the thumb (*Gray s Anatomy*)

Innervation The deep radial nerve with fibers from the sixth and seventh cervical nerves by way of the brachial plexus

Action Abducts the thumb and by continued action the wrist

FLEXOR POLLICIS LONGUS

This is the only flexor of the thumb located in the forearm Since the thumb lacks the second phalanx the flexor sublimis flexor of the second phalanx of the fingers naturally has no counterpart among the thumb muscles The flexor pollicis longus lies beside the flexor profundus in the forearm and is attached to the last phalanx like the latter It can therefore be considered as a part of the deep flexor (Fig 98)

Origin Anterior surface of the middle half of the radius and adjacent parts of the interosseous membrane

Insertion The anterior surface of the base of the last phalanx of the thumb

Innervation The volar interosseous nerve from the median Fibers come from the eighth cervical and first thoracic nerves

Action Flexes the second phalanx of the thumb Continued action flexes the first phalanx and flexes and adducts the metacarpal and wrist

FLEXOR POLLICIS BREVIS

This is the inner of the two short flexors (Fig 98)

Origin The lower part of the ridge of the greater multangular bone and the lower border of the transverse carpal ligament

Insertion Base of the first phalanx of the thumb on the radial side

Innervation The median nerve with fibers from the sixth and seventh cervical nerves

Action Flexion of the first phalanx flexion and adduction of the metacarpal of the thumb

OPPONENS POLLICIS

A small triangular muscle beneath the abductor pollicis brevis

Origin The greater multangular and transverse carpal ligament

Insertion The shaft of the metacarpal bone on its radial side

Innervation The median nerve with fibers from the sixth and seventh cervical nerves

Action Opposition, which is a partial circumduction of the metacarpal of the thumb By its use the tip of the thumb can be made to meet the tips of the four fingers in turn (Fig 102)

ABDUCTOR POLLICIS BREVIS

This is the most superficial muscle of the lateral part of the thenar eminence (Fig 98)

Origin The tuberosity of the navicular and the ridge of the greater multangular bones Another slip originates from the transverse carpal ligament

Insertion The lateral surface of the base of the first phalanx of the thumb

Innervation The median nerve with fibers from the sixth and seventh cervical nerves

Action Flexion of the first metacarpal of the thumb

ADDUCTOR POLLICIS

This is the deepest of the thenar muscles (Figs 102 and 103)

Origin The oblique head arises from the capitate bone the bases of the second and third metacarpals and the intercarpal ligaments The transverse head arises from the lower two thirds of the volar surface of the third metacarpal bone

Insertion The medial surface of the base of the first phalanx of the thumb

Innervation The deep palmar branch of the ulnar nerve Fibers come from the eighth cervical and first thoracic nerves

Action Adduction and hyperadduction of the first metacarpal of the thumb If the thumb is in a position of flexion and hyperadduction it will extend the first metacarpal, bringing it to the surface of the palm

WRIST MOVEMENTS

Actions of the Prime Movers Considering only the prime movers for wrist movements, one prime mover is in excellent position to perform each of the four 'diagonal movements

Flexor carpi radialis	Flexion and abduction
Flexor carpi ulnaris	Flexion and adduction
Extensor carpi radialis (longus & brevis considered as one)	Extension and abduction
Extensior carpi ulnaris	Extension and adduction

None of these prime movers is capable of producing "pure" flexion extension abduction or adduction When such pure movements are desired, there must be helping synergy involving a pair of these prime movers (In *helping synergy* two muscles contract, each cooperating to produce the desired movement and each neutralizing an undesired secondary action of the other)

Flexion—The flexor carpi radialis and the flexor carpi ulnaris both produce flexion The tendency of the former to perform abduction is neutralized by the tendency of the latter to perform adduction, and vice versa

Extension—The extensor carpi ulnaris and the extensor carpi radialis (longus and brevis considered as one) both produce extension The tendency of the former to perform adduction is neutralized by the tendency of the latter to perform abduction and vice versa

Abduction—The flexor carpi radialis and the extensor carpi radialis (longus and brevis) both produce abduction The tendency of the former to perform flexion is neutralized by the tendency of the latter to perform extension and vice versa

Adduction—The flexor carpi ulnaris and the extensor carpi ulnaris both produce adduction The tendency of the former to perform flexion is neutralized by the tendency of the latter to perform extension and vice versa

Actions of the Assistant Movers It is a rule that when a multi joint muscle (*i e* one which crosses more than one joint) contracts it tends to perform movements at each of the joints it crosses A number of long muscles which are primarily designed to cause actions at the more distal joints have their origins on the radius ulna or humerus and thus cross the wrist joint where they tend to perform assistant mover actions The most important are the flexor digitorum sublimis the flexor digitorum profundus and the extensor digitorum communis The potential actions of these long flexors and extensors are summarized as follows (with prime mover actions in upper case)

Flexor digitorum sublimis—wrist flexion METACARPO PHALANGEAL FLEXION FIRST INTER PHALANGEAL FLEXION

Flexor digitorum profundus—wrist flexion metacarpo phalangeal flexion first inter phalangeal flexion SECOND INTER PHALANGEAL FLEXION

Extensor digitorum communis—wrist extension METACARPO PHALANGEAL EXTENSION FIRST INTER PHALANGEAL EXTENSION SECOND INTER PHALANGEAL EXTENSION

According to the usual rule, these muscles would be expected to perform all of their potential actions when they contract individually However, the long flexors and the long extensor interfere with one another as demonstrated in the following experiments

1 With the wrist in full flexion, attempt to perform full finger flexion This is usually impossible because the extensor digitorum communis is not long enough to permit full flexion in all of the joints it crosses

2 With the wrist in full hyperextension attempt to perform full finger extension This is usually impossible because the flexor digitorum sublimis and the flexor digitorum profundus are not long enough to permit full extension in all of the joints they cross

These situations are avoided by use of the prime movers for wrist actions as demonstrated in further experiments

1 Ask a person to make a tight fist (to perform forceful and complete finger flexion) Notice that he unconsciously keeps his wrist in an extended position while doing this Upon palpation the extensor carpi ulnaris and the extensor carpi radialis longus and brevis will be found to be contracting statically These wrist extensors neutralize the tendency of the long finger flexors to produce wrist flexion thereby preventing a limitation of finger flexion due to the shortness of the extensor digitorum communis

2 Ask a person to extend his fingers forcefully and completely Notice that he unconsciously keeps his wrist in a slightly flexed position or at least avoids hyperextension at the wrist Upon palpation the flexor carpi radialis and the flexor carpi ulnaris will be found to be contracting statically These wrist flexors neutralize the tendency of the extensor digitorum communis to produce wrist extension thereby preventing a limitation of finger extension due to shortness of the long finger flexor muscles

In both of the foregoing examples the prime movers for wrist flexion or extension are contracting as true synergists (In *true synergy* a muscle contracts solely for the purpose of neutralizing an unwanted secondary action of the prime movers)

Regarding these phenomena some practical observations may be made When either strong finger flexion or strong finger extension is desired, the most stable position of the wrist is that of extension avoiding any marked flexion or hyperextension The extended (but not hyperextended) position of the wrist provides the most stable anatomical position for the boxer s tightly closed fist for grasping a bat hammer axe, tennis racket or other implement and for withstanding the impacts of wrestling boxing or judo The position is natural but in sports an occasional performer needs to be coached with regard to his wrist position Therapists will note that paralysis of the main wrist extensors prevents effective grasping of small objects with the fingers although custom made braces to hold the wrist in extension may be useful in restoring the function

FINGER MOVEMENTS

The Dorsal Expansion, or Extensor Expansion The mechanism of finger extension cannot be explained rationally if only the direct bony insertions of the finger muscles are considered It is necessary to understand complex

WRIST MOVEMENTS

Actions of the Prime Movers Considering only the prime movers for wrist movements one prime mover is in excellent position to perform each of the four diagonal movements

Flexor carpi radialis	Flexion and abduction
Flexor carpi ulnaris	Flexion and adduction
Extensor carpi radialis (longus & brevis considered as one)	Extension and abduction
Extensior carpi ulnaris	Extension and adduction

None of these prime movers is capable of producing pure flexion extension, abduction, or adduction When such pure movements are desired, there must be helping synergy involving a pair of these prime movers (In *helping synergy* two muscles contract each cooperating to produce the desired movement, and each neutralizing an undesired secondary action of the other)

Flexion—The flexor carpi radialis and the flexor carpi ulnaris both produce flexion The tendency of the former to perform abduction is neutralized by the tendency of the latter to perform adduction, and vice versa

Extension—The extensor carpi ulnaris and the extensor carpi radialis (longus and brevis considered as one) both produce extension The tendency of the former to perform adduction is neutralized by the tendency of the latter to perform abduction and vice versa

Abduction—The flexor carpi radialis and the extensor carpi radialis (longus and brevis) both produce abduction The tendency of the former to perform flexion is neutralized by the tendency of the latter to perform extension and vice versa

Adduction—The flexor carpi ulnaris and the extensor carpi ulnaris both produce adduction The tendency of the former to perform flexion is neutralized by the tendency of the latter to perform extension, and vice versa

Actions of the Assistant Movers It is a rule that when a multi joint muscle (*i e* one which crosses more than one joint) contracts it tends to perform movements at each of the joints it crosses A number of long muscles, which are primarily designed to cause actions at the more distal joints have their origins on the radius, ulna or humerus and thus cross the wrist joint, where they tend to perform assistant mover actions The most important are the flexor digitorum sublimis the flexor digitorum profundus and the extensor digitorum communis The potential actions of these long flexors and extensors are summarized as follows (with prime mover actions in upper case)

Flexor digitorum sublimis—wrist flexion METACARPO PHALANGEAL FLEXION FIRST INTER PHALANGEAL FLEXION

Flexor digitorum profundus—wrist flexion metacarpo phalangeal flexion first inter phalangeal flexion SECOND INTER PHALANGEAL FLEXION

Extensor digitorum communis—wrist extension METACARPO PHALANGEAL EXTENSION FIRST INTER PHALANGEAL EXTENSION SECOND INTER PHALANGEAL EXTENSION

cales, and some of the thenar and hypothenar muscles It is basically triangular, with a broad base or *hood* created from lateral slips spreading from the extensor digitorum communis tendon at the level of the metacarpo phalangeal joint This hood is partly wrapped around the sides of the proximal end of the first phalanx enclosing the direct bony insertion of the interosseous muscles Just distal to the hood, the interosseous muscles each send a tendon into the extensor expansion, forming the sides of the triangle, called the *lateral bands* Just distal to these, at the shaft of the first phalanx the lumbricales also insert into the extensor expansion The lateral bands converge distally and attach to the dorsal surface of the proximal end of the third phalanx The main tendon of the extensor digitorum communis forms the centrally-located *middle slip* of the extensor expansion, which inserts on the dorsal surface of the proximal end of the second phalanx The middle slip also receives fibers from the interossei and the lumbricales likewise, the extensor digitorum communis tendon expands outward and contributes to the lateral bands

The extensor expansion permits the extensor digitorum communis to extend the terminal phalanx of the digits as well as the more proximal second phalanx and first phalanx The lumbricales and interossei, however enter the extensor expansion at the lateral bands and at the part of the hood which is curved around the sides of the bases of the first phalanx, in such a manner as to cause flexion of the first phalanx (at the metacarpo phalangeal joint) and extension of the second and third phalanges Only because of this mechanism are such acts as writing and needle threading possible These activities require metacarpo phalangeal flexion and inter phalangeal extension These actions can be performed by the lumbricales and interossei, but not by the extensor digitorum communis Paralysis of the lumbricales and interossei leaves only the extensor digitorum communis to extend the inter phalangeal joints Their unaided action causes simultaneous extension of the metacarpo phalangeal joint making impossible the many fine hand actions requiring extension of the distal phalanges along with flexion of the first phalanx In other words such paralysis leaves only the possibility of flexion of all the phalanges by the long finger flexors or extension of all the phalanges by the long finger extensor

If it is desired to perform extension of the first phalanx *with simultaneous* flexion of the second and third phalanges contraction of the extensor digitorum communis and of the long finger flexors will produce the wanted result

Individuality of Finger Flexion and Extension The flexor digitorum sublimis and the flexor digitorum profundus each are composed of separate bundles of fibers which may be stimulated separately to activate the long flexor tendons of the four fingers individually Typing and playing some musical instruments depends upon learning these individuations The extensor digitorum communis is unable to move the fingers independently to the same degree as the flexors, because of three fibrous bands which interconnect the extensor tendons across the back of the hand (Fig 97) The ring finger is especially limited in this way However the index finger and the little finger are provided with their own small extensor muscles, the extensor indicis proprius and the extensor digiti quinti proprius respectively These small muscles are inserted into the corresponding

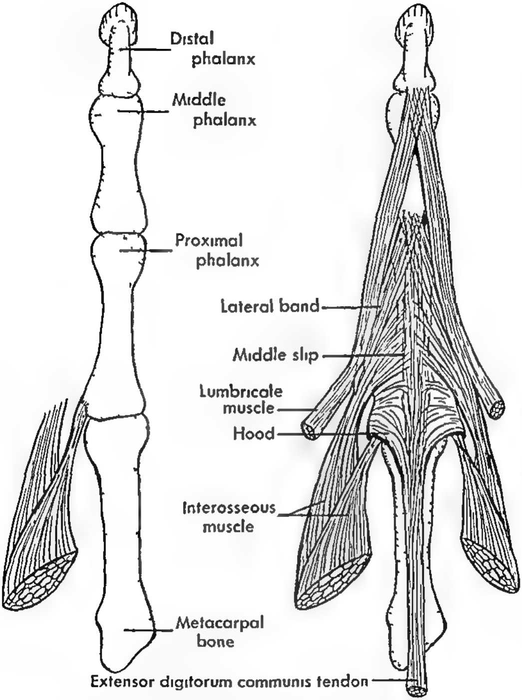

FIG 103 —The dorsal (extensor) expansion (Douglas after Grant)

and highly specialized tendinous branchings known as the *dorsal expansion* or *extensor expansion*

An extensor expansion is found on the dorsal aspect of each digit with a somewhat modified structure for the thumb A diagram of the essential architecture of the extensor expansion is shown in Fig 103

The structure consists of systematic ramifications of the tendons of insertion of the extensor digitorum communis the interosseous muscles the lumbri

finger tips closer to the palm, while the abductor pollicis longus acts with the flexors longus and brevis pollicis to accomplish the same result on the thumb side

Experts on accident insurance estimate the value of the thumb at half that of the whole hand Its usefulness is largely due to its position of opposition to the fingers and the resulting ability to grasp and hold objects between them In the finer work in which man excels all other animals certain tools are manipulated by action of the fingers and thumb In such work the muscles of the thenar eminence are of greatest value in moving the thumb The hand of man differs from that of the anthropoid apes mainly in the greater development of the muscles of the thenar eminence and in the habitual position of the thumb, which is one of much more nearly complete opposition to the fingers It has been theorized that every skilled musician, instrument maker, slight of hand artist and pickpocket must have hands that are constructed in such a way as to make them adaptable to his peculiar task [1] This suggestion needs to be investigated, but there is no movement of the hand which a man can make that a monkey cannot The difference lies in the fact that man is more capable of purposive actions Human skill is a result of an elaboration of the central nervous system and not of a specialization of the hand, which is actually a relatively primitive structure [2]

PREHENSILE MOVEMENTS

It is to be noted that the nature of the grip is actually dictated by the nature of the intended activity Napier[2] contends that all movements of the hand may be divided into two main groups prehensile movements, in which an object is seized and held wholly or partly within the grasp of the hand and non prehensile movements, in which objects are manipulated by pushing or lifting Prehensile movements may be further subdivided into a power grip in which the object is clamped by the partly flexed fingers and palm with counter pressure applied by the thumb lying more or less in the plane of the palm and a precision grip in which the object is pinched between the fingers and the opposing thumb The position of the thumb shows a fundamental difference in the two prehensile grips In the power grip it is adducted at both the metacarpo phalangeal and carpo metacarpal joints The hand is deviated toward the ulnar side, and the wrist is held in the neutral position In the precision grip the thumb is abducted and medially rotated, the hand is held midway between radial and ulnar deviation, and the wrist is markedly dorsi flexed However, very heavy objects are often held in the clenched fist with the thumb fully adducted

A more detailed analysis of the various types of prehension is shown in Figure 104 In all of these grips the hand assumes a fixed position and is maintained therein by the cocontraction of the opposing muscles Each of the muscles of the wrist functions as an agonist a stabilizer, or an antagonist as the load shifts The maximum prehensile force is obtained at a wrist angle of about 145 degrees In extreme positions of wrist angle the marked stretching or slackening of the wrist muscles results in a reduction of strength In rest with the hand hanging loosely at the side the wrist takes a mid position and the hand is dorsiflexed 35 degrees with respect to the extended forearm axis This is its position of greatest prehensile force [3]

tendon of the extensor digitorum communis and into the extensor expansions, along with other small individual finger muscles, thus permitting an amazing versatility of fine finger movements Paralysis of even a few of the various finger muscles will reduce the functional ability of the hand to that of a paw

Extensors of the Inter-phalangeal Joints When the metacarpo phalangeal joint is held in extension, the extensor digitorum communis muscle is primarily responsible, but it does not have sufficient shortening ability to extend the two inter phalangeal joints at the same time Under these conditions, the lumbricales and the interossei being on stretch because of the metacarpo phalangeal extension become prime movers for extension of the inter phalangeal joints

The situation is reversed when the metacarpo phalangeal joint is held in flexion Then, the lumbricales and interossei have expended their shortening ability in causing metacarpo phalangeal flexion, and are unable to contract further so as to cause extension at the inter phalangeal joints However the extensor digitorum communis is on stretch because of the metacarpo phalangeal flexion and therefore can use its shortening power to become a prime mover for the inter phalangeal extension

THUMB MOVEMENTS

Opposition of the thumb to the fingers is a unique action Although the adductor pollicis and the flexor pollicis longus and brevis participate in opposition, the contraction of the opponens is the crucial factor When the opponens is paralyzed, true opposition is impossible, even though thumb adduction and thumb flexion at both metacarpo phalangeal and inter phalangeal joints are unaffected

When forcibly closing the fist or in the simple use of the hand, such as grasping the handle of a hammer the abductor pollicis draws the thumb away from the hand while the opponens pollicis rotates the metacarpal of the thumb bringing it out in front of the palm to face the fingers The fingers are flexed by contraction of the flexors sublimis and profundus This is accompanied or closely followed by contraction of the adductor pollicis and the flexors of the thumb together with extension of the wrist to complete the movement

In chopping and in using a hammer there is also strong adduction of the wrist In the use of coarse tools such as the axe hammer, saw, plane and wrench it is mainly the three flexors of the thumb that come into action In finer work such as the use of a pen pencil needle or other small instruments where the tips of the thumb and fingers must be brought together, it is necessary to keep the thumb in opposition and flex the first phalanx of the fingers to nearly a right angle because the thumb is so much shorter than the fingers

Writing with a pen or pencil and using the so called finger movement requires the use of many muscles The grasping of the pen between the thumb and the next two fingers calls into action the flexors profundus and sublimis The three flexors of the thumb along with the abductor are likewise required To make an up stroke with the pen the lumbricales and interossei contract and extend the last two phalanges while still further flexing the first in the thumb a similar movement takes place the metacarpal bone being flexed on the wrist and the other joints extended Then to make a down stroke the two flexors of the fingers join with the extensor communis in order to pull the

TABLE 10 —Actions of the Wrist and Hand Muscles

	WRIST				METACARPO PHALANGEAL				INTER PHALANGEAL 1st		INTER PHALANGEAL 2nd		CARPO METACARPAL OF THUMB				
	Flexion	Extension	Abduction	Adduction	Flexion	Extension	Abduction	Adduction	Flexion	Extension	Flexion	Extension	Flexion	Extension	Abduction	Adduction	Opposition
Flexor carpi radialis	P M		P M														
Flexor carpi ulnaris	P M			P M													
Palmaris longus	Asst																
Extensor carpi radialis longus		P M	P M														
Extensor carpi radialis brevis		P M	P M														
Extensor carpi ulnaris		P M		P M													
Flexor digitorum profundus	Asst				Asst				P M		P M						
Flexor digitorum sublimis	Asst				P M				P M								
Extensor digitorum communis		Asst				P M				P M		P M					
Extensor indicis proprius		Asst				P M		Asst		P M		P M					
Extensor digiti quinti propius		Asst				P M				P M		P M					
Lumbricales					P M		Asst			P M		P M					
1st & 2nd Dorsal Interossei					Asst		P M			Asst		Asst					
3rd & 4th Dorsal Interossei					Asst			P M		Asst		Asst					
1st Palmar Interosseous					Asst		P M			Asst		Asst					
2nd & 3rd Palmar Interossei					Asst			P M		Asst		Asst					
Abductor digiti quinti					Asst			P M									
Flexor digiti quinti brevis					P M												
Opponens digiti quinti					P M												
Extensor pollicis longus		Asst				P M				P M				P M			
Extensor pollicis brevis			Asst			P M									P M		
Abductor pollicis longus			Asst												P M		
Flexor pollicis longus	Asst			Asst	P M				P M				P M			P M	
Flexor pollicis brevis					P M								P M			P M	
Opponens pollicis																	P M
Abductor pollicis brevis													P M				
Adductor pollicis														P M		P M	

Grip Strength In a study of 552 male industrial workers the median grip strength of the preferred hand was 49 3 kg , while that of 96 female workers was 35 0 kg [4] The maximum grip strength is found during the mid twenties, by age sixty there is a decline of 16 5 per cent [5]

Implications for Athletic Training Traumata to the hands are relatively frequent in such sports as boxing football and baseball Fractures of the finger and hand bones are the most common of all fractures resulting from sports activities The metacarpo phalangeal and inter phalangeal joints are especially subject to degenerative fibrotic changes when the hand is immobil ized At the first appearance of circulatory stasis or stiffness in the fingers

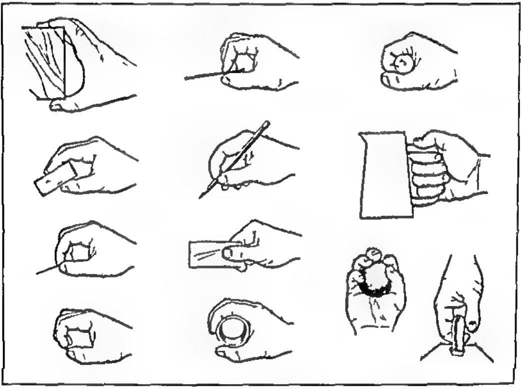

Fig 104 —Twelve basic types of grasp (Courtesy of Artificial Limbs After Schlesinger)

moist heat massage and exercises should be started [6] Squeezing of small rubber balls is often recommended but these are usually of such a size that only partial flexion of the fingers is achieved Foam rubber or plastic putty are more useful All too often flexion exercises are prescribed when the fingers are already in a state of partial contracture and the actual need is for a strength ening of the extensors and a stretching of the flexors

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	Flexion	Extension	Abduction	Adduction	Flexion	Extension	Abduction	Adduction	Flexion	Extension	Flexion	Extension	Flexion	Extension	Abduction	Adduction	Opposition
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Flexor digitorum profundus	Asst				Asst				P M		P M						
Flexor digitorum sublimis	Asst				P M				P M								
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Extensor indicis proprius		Asst				P M		Asst		P M		P M					
Extensor digiti quinti propius		Asst				P M				P M		P M					
Lumbricales					P M		Asst			P M		P M					
1st & 2nd Dorsal Interossei					Asst		P M			Asst		Asst					
3rd & 4th Dorsal Interossei					Asst			P M		Asst		Asst					
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Extensor pollicis longus		Asst				P M				P M				P M			
Extensor pollicis brevis			Asst			P M									P M		
Abductor pollicis longus			Asst												P M		
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Flexor pollicis brevis					P M								P M			P M	
Opponens pollicis																	P M
Abductor pollicis brevis													P M				
Adductor pollicis														P M		P M	

3 Taylor, Craig L and Schwarz, Robert J The Anatomy and Mechanics of the Human Hand Artificial Limbs, *2* 22–35, 1955

4 Fisher, M Bruce and Birren James E Standardization of a Test of Hand Strength J Appl Psychol *30* 380–387 1946

5 ——— Age and Strength *J Appl Psychol*, *31* 490–497 1947

6 Bilik S E Prevention of Superimposed Disabilities New York State J Med *54* 1625–1628, 1954

LABORATORY EXERCISES

1 Study the number of tendons nerves and blood vessels which traverse the wrist and hand areas Are these well protected from possible incisions?

2 With the wrist completely hyperextended try to extend the fingers completely Discuss the reasons why this is difficult or impossible

3 Completely flex the wrist and attempt to flex the fingers completely Why is this impossible?

4 Extend the fingers Explain why they tend to spread apart

5 Using a goniometer measure the amount of abduction and adduction of the wrist Measure the amount of flexion and extension of the wrist with the fingers extended and with the hand tightly clenched

6 Grasp a stick having about the same diameter as a broom handle Have a laboratory partner forcibly flex your wrist and measure the angle of flexion when you are obliged to release the stick

7 Using a hand dynamometer, measure the strength of the grasp in wrist hyper extension neutral position and flexion

8 Using a goniometer measure the entire range of rotation of the extended arm There is some rotation in the midcarpal joint Does the value just measured exceed the sum of shoulder joint rotation and radio ulnar pronation supination?

Chapter 13

Movements of the Pelvic Girdle and the Hip-Joint

EVERYONE is familiar with resemblances between the upper and lower limbs However the pelvic girdle which corresponds to the shoulder girdle, is not movable in the same manner as the latter with the consequence that the entire set of movements and muscles studied in Chapter 9 has no counterpart in the lower limb

THE PELVIS

Each half of the pelvic girdle consists of three bones, the *ilium* above at the side of the hip the *pubis* below and forward and the *ischium* below and to the rear They are separate in early life but in the adult are joined to form one solid structure the *innominate* or hip bone The pelvic basin is closed posteriorly by the sacrum which is wedged between and attached to the two innominate bones The joint formed by the sacrum and the ilium is *amphiarthrodial* held by three strong ligaments the anterior and posterior sacroiliac and the interosseous ligaments The possibility of movement in the sacroiliac joint is greatly reduced by the presence of interlocking convolutions on the two articulating surfaces So immobile are the joints the sacrum forms with the two innominate bones that for most purposes the entire structure may be regarded as one single bone

The pelvis is tied together at the pubic symphysis the two pubes being separated by a heavy disc of fibrocartilage This is also a tight joint and is heavily reinforced by ligaments, the superior pubic above and the arcuate pubic beneath and by ligamentous tissue associated with the interpubic disc The ligaments of both the pubis and sacroiliac joints relax somewhat during pregnancy permitting some movement and expansion of the pelvis

Because the pelvic girdle including the sacrum, acts as a unit the lumbosacral joint becomes the important articulation when the pelvis moves in relation to the spine This joint is supported by ligaments in a manner quite similar to that of the other nearby intervertebral joints

3 Taylor, Craig L and Schwarz, Robert J The Anatomy and Mechanics of the Human Hand Artificial Limbs, *2* 22–35, 1955

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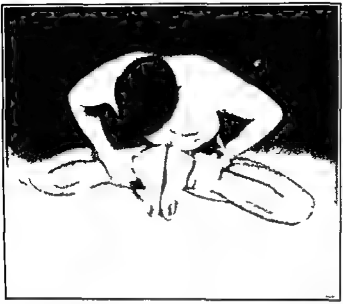

FIG 106—Swami Vishnudevananda demonstrating the remarkable flexibility of the hip knee and ankle joints achieved from practice of yogi exercises Roentgenographic examination of the pelvis knees ankles and feet disclosed no evidence of traumatic or pathologic changes [1] (O Connell courtesy C O P &S)

ball and socket joint, having less freedom of motion than the shoulder joint, the socket being deeper and the bones fitting so closely that much force is required to pull it apart However in a trained person a surprisingly large degree of flexibility can be demonstrated (Fig 106) The usual capsular ligament is present and is thickened on the anterior side by the *ilio femoral band,* or the *inverted Y ligament* on the antero inferior side the *pubo capsular ligament* and on the posterior the *ischio capsular ligament* (Fig 107)

FUNDAMENTAL MOVEMENTS OF THE HIP-JOINT

The femur is the longest bone in the body and corresponds in a way to the humerus like the humerus it has a head shaft and two condyles in place of tuberosities it has two large prominences the great and small *trochanters* along the back of the shaft is the *linea aspera* or rough line

Flexion The hip joint permits movement of the femur most freely forward this is called flexion it can take place through 150 degrees or more when it is stopped by contact of the thigh with the front of the trunk When the knee is extended the hip joint can be flexed only to the extent of a right angle but this is due to tension of the hamstring muscles and not to the form of the joint

Extension The reverse of flexion movement of the femur downward and backward is called extension and is free until the limb is vertically downward in line with the trunk when it is stopped by tension of the ilio femoral band and of the psoas and iliacus muscles making any hyperextension of the hip joint impossible in normal subjects Careful examination will show that in apparent hyperextension of the hip-joint which occurs when one pushes one limb as far back as possible while standing on the other limb the pelvis tilts forward with the moving femur, the movement really being a slight flexion of the other hip-joint and slight hyperextension of the spinal column in the

FUNDAMENTAL MOVEMENTS OF THE PELVIS

Most movements of the pelvis are for the purpose of aligning the pelvis in order to provide greater ease or range of motion of either the trunk or the lower extremities When we bend over to tie a shoe lace the pelvis tilts or rotates to accommodate the movement of the trunk If the thigh is flexed on the trunk as when punting a football, the pelvis rotates in order to increase the range of motion of the thigh with reference to the trunk Movements of the pelvis are more properly considered as spinal movements occurring at the lumbosacral articulation They may be conveniently classified as follows

1 Forward rotation or tilt Increased inclination resulting from lumbo sacral hyperextension and in the erect position hip flexion

2 Backward rotation or tilt Decreased inclination resulting from lumbo sacral flexion (reduction of hyperextension) and, in the erect position hip extension

3 Lateral tilt The lowering or raising of one iliac crest with reference to its contralateral mate

4 Rotation Turning about a vertical axis either to the right or to the left

THE HIP JOINT

The hip joint is formed by the articulation of the head of the femur with the *acetabulum* (Fig 105) which is the name given to the socket on the outer surface of the hip bone just where the ilium pubis and ischium join It is a

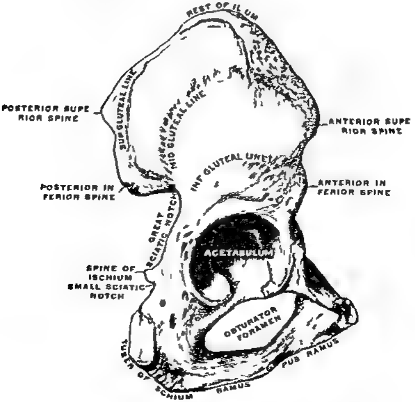

FIG 105 —The hip bone of right side outer surface

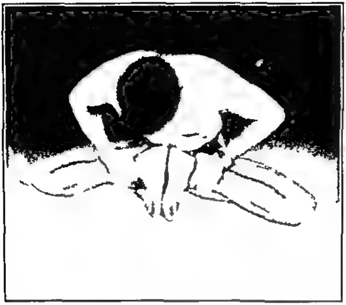

FIG 106—Swami Vishnudevananda demonstrating the remarkable flexibility of the hip knee, and ankle joints achieved from practice of yogi exercises Roentgenographic examination of the pelvis knees ankles and feet disclosed no evidence of traumatic or pathologic changes [1] (O Connell courtesy C O P &S)

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lumbar region Horizontal flexion and horizontal extension of the hip joint can also be differentiated but these have little practical application and will not be considered here

Abduction Movement of one limb away from the other toward the side is called abduction, and is usually possible through 45 degrees or more The limitation here is due to resistance of opposing muscles, the joint itself permitting nearly 90 degrees of abduction, especially if the toes are turned outward *Abduction may also take place by movement of the trunk* for example, the right hip joint is abducted by inclining the trunk to the right while standing on the right foot

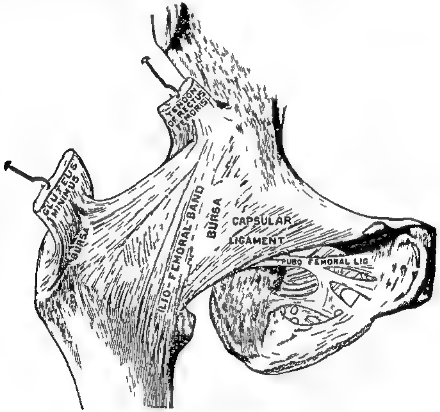

FIG 107 —Right hip joint front view

Adduction Adduction is limited by contact of the moving limb with the other limb it can take place further when the moving limb is a little front or rear from the other or when the trunk is inclined to the side as in the last example the right hip joint is also adducted when the left hip is dropped below the level of the right while standing on the right leg

Circumduction Movement of the limb in a circular manner by a combination of the four movements above described is called circumduction turning the limb on its central axis is called rotation This axis is a line through hip and knee joints passing considerably inside of the shaft of the femur because of the sharp bend of that bone near the trochanters

Rotation Rotation is possible through about 90 degrees and is said to be outward or inward according to the way the toes are turned Because of

the sharp bend of the femur just mentioned, the neck of the femur strikes the side of the socket and limits the movement called rotation of the limb The way the bones come in contact explains why flexion is so free and why rotation is so limited

MUSCLES ACTING ON THE HIP-JOINT

There are sixteen muscles acting on the hip joint besides a group of six smaller ones, they are classified for our purposes as follows

Six *flexors* psoas iliacus sartorius, pectineus, rectus femoris, tensor fasciae latae

Four *extensors* gluteus maximus biceps femoris semitendinosus semimembranosus

Two *abductors* gluteus medius gluteus minimus

Four *adductors* gracilis, adductor longus adductor brevis adductor magnus

Six *outward rotators* pyriformis obturator externus, obturator internus, gemellus superior, gemellus inferior, quadratus femoris

PSOAS

Nearly all the psoas lies in the abdominal cavity behind the internal organs, where it cannot be easily observed *in vivo* It is usually called the 'psoas magnus' to distinguish it from a small muscle associated with it in most vertebrate animals and called the psoas minor The latter muscle is often absent in man (Fig 109)

Origin The sides of the bodies of the last thoracic and all the lumbar vertebrae and their intervertebral cartilages The anterior surfaces and lower borders of the transverse processes of all the lumbar vertebrae

Insertion The small trochanter of the femur

Innervation Branches of the femoral nerve from the lumbar plexus which contain fibers from the second and third lumbar nerves

Structure Muscle fibers arising directly from the bodies of the vertebrae and attaching obliquely into the tendon of insertion

Action The line of pull of the psoas is indicated by a string tied around the shaft of the femur with the knot just below the small trochanter and the free end held beside the bodies of the lumbar vertebrae, passing across the front of the pelvis in a notch just in front of the hip joint Notice that the small trochanter while it is on the inner side of the femur, is so nearly on the axis of rotation that the psoas can have little rotary effect, and that the pull is so directly across the front of the joint that it will tend to flex the hip

Looking at the string used to represent the psoas from a position at the side of the skeleton we can see that the origin of the muscle is farther to the rear than its insertion, that it makes a considerable angle where it pulls across the edge of the pelvis and that as a result it pulls forward on the femur at a fairly favorable angle in spite of the fact that its origin is so far back By lifting the femur forward and upward and noticing the angle of pull it is apparent that the leverage improves as the limb is raised The turn across the front of the pelvis also gives the psoas considerable leverage in pulling the spinal column forward and this action will be discussed further in Chapter 16

The psoas is especially well adapted to work where the hip joint and spinal

lumbar region Horizontal flexion and horizontal extension of the hip joint can also be differentiated, but these have little practical application and will not be considered here

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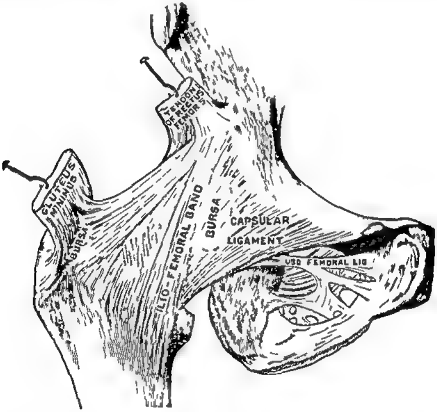

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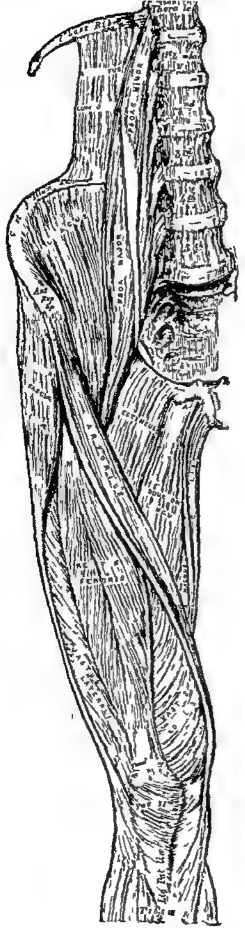

FIG 109—Muscles of the iliac and anterior femoral regions (*Gray's Anatomy*)

column are flexed at the same time as in rope climbing and similar exercises The capacity of this muscle to act rapidly is extremely important in many athletic activities If it is weak, it is difficult to advance the limb when walking, if both psoas muscles are paralyzed it is difficult to raise the body from a supine to a sitting position [2] It is practically impossible to observe its action in a normal subject

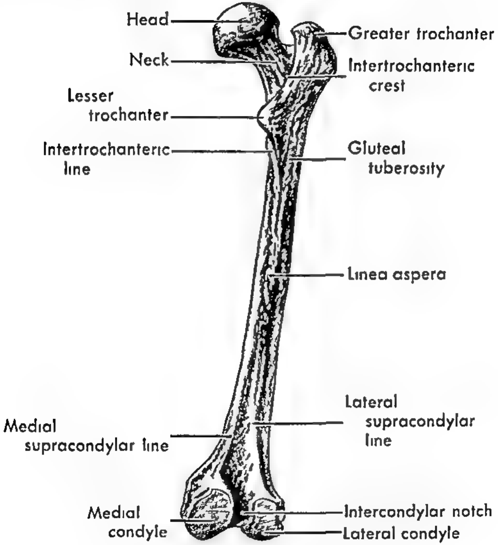

FIG 108 —Right femur rear view (Douglas)

ILIACUS

A flat triangular muscle named from the bone on which it has its origin (Fig 109)

Origin The inner surface of the ilium and a part of the inner surface of the sacrum near the ilium

Insertion Its tendon joins that of the psoas just where the latter crosses the front of the pelvis, to attach with it on the small trochanter

ing a football It is the only muscle that could do this alone and therefore might be properly called the ' kicking muscle It forms a conspicuous ridge down the front of the thigh as it contracts and can be seen and felt in action in all movements of combined flexion of the hip and extension of the knee Its action on the knee will be discussed further in connection with the muscles extending the knee

PECTINEUS

A short thick muscle just below the groin partly covered by the sartorius and the rectus femoris (Figs 109 219, 222)

Origin A space an inch wide on the front of the pubes just below the rim of the pelvic basin between the iliopectineal eminence and the tubercle of the pubis

Insertion A rough line leading from the lesser trochanter to the linea aspera

Innervation A branch of the femoral nerve with fibers from the second, third and fourth lumbar nerves

Structure Penniform, both ends of the muscle having muscular and tendinous fibers intermingled It is twisted through 90 degrees as it passes from the origin to insertion

Action The pectineus is a prime mover for hip joint flexion and adduction It is a weak assistant for outward rotation The power arm of the pectineus is several inches long and its angle of pull about 60 degrees indicating lifting power rather than speed of movement Leverage improves as the femur is moved forward and inward

The pectineus can alone lift the thigh while the subject is sitting and place it across the other thigh It is used in practically all vigorous flexion of the hip especially in motions requiring force rather than speed

TENSOR FASCIAE LATAE

A small muscle at the front and side of the hip called tensor fasciae latae or tensor vaginae femoris from its action to tighten the fascia of the thigh It is peculiar in having no bony insertion (Fig 109)

Origin The iliac crest in the region of the anterior superior spine of the ilium

Insertion The iliotibial band of the fascia lata of the thigh one fourth of the way down the outside of the thigh

Innervation A branch of the superior gluteal nerve from the femoral plexus It contains fibers from the fourth and fifth lumbar nerves and the first sacral nerve

Structure The muscle lies between two layers of the fascia and the longitudinal muscle fibers are inserted into these two layers

Action A prime mover for inward rotation and an assistant for flexion and abduction of the hip joint According to Hamilton [2] this muscle may hypertrophy if the psoas is paralyzed

The tensor fasciae latae affords a good example of the amazing strength of human muscle Parallel arrangement of heavy fiber fascia and tendon gives great strength in the direction in which the muscle is subject to strain In one group of cadavers the average tensile strength of this muscle was 7,000 pounds

Innervation Branches from the femoral nerve from the lumbar plexus Fibers come from the second and third lumbar nerves

Structure Muscle fibers arising directly from the ilium and joining the tendon obliquely

Action Hip joint flexion Since the psoas and iliacus have a common tendon of insertion, they are frequently referred to jointly as the iliopsoas However it cannot act on the joints of the spine as does the psoas

SARTORIUS

The name means tailor s muscle ' so called because the ancient anatomists noticed that it is the muscle used in crossing the legs to take the position Oriental tailors assume at their work It is the longest muscle in the body, and is capable of a greater extent of contraction than any other (Fig 109)

Origin The anterior superior iliac spine and the upper half of the notch just below it

Insertion Lower anterior part of the medial surface of the tuberosity of the tibia

Innervation Two branches from the femoral nerve containing fibers from the second and third lumbar nerves One branch serves the proximal portion of the muscle the second branch the distal portion

Structure Parallel longitudinal fibers The muscle lies between two layers of the fascia of the thigh and some of its fibers are inserted into the fascia half way down the thigh The muscle curves around the inner side of the thigh passing behind the inner condyle and then forward to its insertion

The fascia of the thigh is a thick sheet of fibrous connective tissue that envelops the thigh just under the skin

Action Directly assists in flexion, abduction and outward rotation of the thigh at the hip joint knee flexion and knee inward rotation [3]

RECTUS FEMORIS

This large muscle named from its position straight down the front of the thigh, corresponds closely to the long head of the triceps on the arm being the middle part of a three headed extensor (Fig 109)

Origin The antero inferior spine of the ilium between its tip and the hip joint and a second head the posterior from a groove above the edge of the acetabulum

Insertion The proximal border of the patella

Innervation The femoral nerve fibers come from the second third, and fourth lumbar nerves

Structure The upper tendon passes down the middle of the muscle and the flattened lower tendon passes up beneath its deeper surface The muscle fibers cross obliquely from one tendon to the other

Action The rectus femoris is a prime mover for hip joint flexion and assists with hip joint abduction [3] It possesses a very short power arm and a pull nearly in line with the femur favorable for speed but not for force there is very little change in leverage when the limb is lifted Any force keeping the knee flexed will make the tension on the rectus femoris much greater

Isolated action of the rectus femoris causes flexion of the hip and extension of the knee with great speed and power giving the motion employed in kick

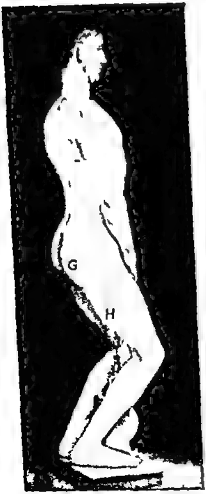

FIG 111 —The extensors of the hip in action *G* gluteus maximus *H* ham string group

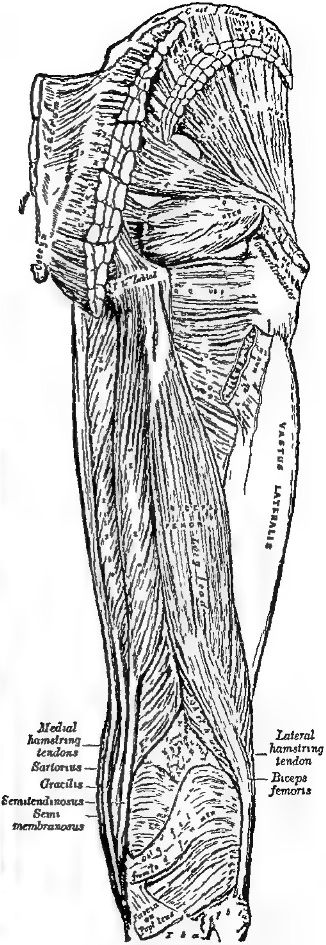

FIG 112 —Superficial muscles of the back of the thigh (*Gray's Anatomy*)

per square inch This compares favorably with that of soft steel wire of the same weight The elasticity (capacity to return to original dimensions under limited maximum safe stress) of this muscle was above 91 per cent [4]

GLUTEUS MAXIMUS

A very large fleshy muscle at the back of the hip (Fig 110 and 111)

Origin The outer surface of the ilium along the posterior one fourth of its crest the posterior surface of the sacrum close to the ilium the side of the coccyx and the fascia of the lumbar region

Insertion A rough line about 4 inches long on the posterior aspect of the femur between the greater trochanter and the linea aspera and the iliotibial band of the fascia lata

Fig 110 —Gluteus maximus of right side

Innervation The inferior gluteal nerve from the femoral plexus Fibers come from the fifth lumbar and first and second sacral nerves

Structure Muscular fibers arising directly from the pelvis and making an oblique junction with the tendon of insertion which is a flat sheet extending up from the femur and along the posterior edge of the muscle

Action Extension and outward rotation at the hip joint Upper fibers assist with abduction lower fibers assist with adduction The gluteus maximus being superficial can easily be palpated It contracts in raising the trunk from a position of inclination forward and from a position in which the knees are bent deeply but it ceases to act before the erect position is reached It

Structure The short muscle fibers pass diagonally downward from the tendon of origin to join the tendon of insertion, the bulk of the muscle being in the upper half of the thigh

Action Extends the thigh and assists in inward rotation of the hip joint At the knee it is a prime mover for flexion and inward rotation

SEMIMEMBRANOSUS

This muscle, which is named from its membranous tendon of origin, lies on the posterior and medial aspect of the thigh (Fig 112)

Origin The tuberosity of the ischium

Insertion The posterior medial aspect of the medial condyle of the tibia. The tendon of insertion of this muscle forms one of the medial hamstrings

Innervation Branches from the tibial portion of the sciatic nerve The fibers are from the fifth lumbar and first two sacral nerves

Structure Similar to the preceding muscle but a longer upper tendon and a shorter lower one brings the muscular mass lower down

Action Extends the thigh and assists in inward rotation of the hip joint At the knee it is a prime mover for flexion and inward rotation

GLUTEUS MEDIUS

A short thick muscle situated at the side of the ilium and giving the rounded contour to the side of the hip (Fig 112)

Origin The outer surface of the ilium near its crest between the posterior gluteal line above and the anterior gluteal line below

Insertion The oblique ridge on the lateral surface of the greater trochanter

Innervation Branches of the superior gluteal nerve from fibers of the fourth and fifth lumbar and first sacral nerves

Structure The fibers arise directly from the ilium and converge to a penniform junction with the flat tendon of insertion

Action The power arm of the gluteus medius, which is a straight line from the top of the trochanter to the center of the hip joint, is an unusually long one and the muscle pulls upon it at almost a right angle, giving it great mechanical advantage The gluteus medius is a powerful abductor of the hip joint The anterior fibers assist with inward rotation and flexion the posterior fibers with outward rotation and extension In the erect position when a limb is raised off the ground the pelvis tends to drop on that side (Trendelenburg s sign) This is prevented by contraction of the opposite gluteus medius

GLUTEUS MINIMUS

A smaller companion of the preceding lying just beneath it (Fig 112)

Origin The lower part of the outer surface of the ilium

Insertion The front part of the top of the great trochanter

Innervation Branches of the superior gluteal nerve from fibers of the fourth and fifth lumbar and first sacral nerves

Structure Similar to the medius

Action The anterior fibers cause strong inward rotation at the hip joint and assist with flexion The posterior fibers assist with outward rotation and extension The whole muscle assists with abduction

can be observed similarly that it acts in raising the body from sitting to standing, and in walking up stairs or up a steep incline It contracts vigorously in jumping but in easy walking remains relaxed except as used to check the momentum of the limb at the end of the forward swing These peculiarities in the action of the gluteus maximus are instances of the working of a rule governing the coordination of extension of the hip somewhat similar to one pertaining to the upward rotation of the scapula in which the lower serratus magnus fails to work in certain positions The rule seems to be that the gluteus maximus is not called into action in extension of the hip until the hip is flexed in excess of about 45 degrees unless there is strong resistance when the angle of limitation is less The rule explains the tendency of bicyclists to stoop forward the demonstrated advantage of the crouching start in sprint racing and the tendency of old people to incline forward in going up stairs In all such instances the position gives the person stronger use of the gluteus maximus

Persons who have lost the use of the gluteus maximus walk normally, but cannot go up stairs nor up an incline without extreme fatigue, and running jumping or dancing quickly exhausts them

BICEPS FEMORIS

Similar in several respects to the biceps brachii (Fig 112)

Origin The long head from the tuberosity of the ischium, the short head from the lateral lip of the linea aspera

Insertion The lateral condyle of the tibia and the head of the fibula The tendon of insertion of this muscle forms the lateral hamstring

Innervation The long head is supplied by two branches from the tibial portion of the sciatic nerve and contains fibers from the first second and third sacral nerves The short head is served by branches from the peronal portion of the sciatic nerve and contains fibers from the fifth lumbar and the first and second sacral nerves

Structure The tendon of origin is long and flat and forms a septum between the biceps and the semitendinosus the lower tendon extends half way up the thigh The muscle fibers are short and pass obliquely downward from the upper tendon and the femur to join the lower tendon

Action Only the long head acts at the hip joint It is a prime mover for extension and an assistant for outward rotation Both heads act as prime movers for flexion and outward rotation at the knee

SEMITENDINOSUS

Named from its long tendon of insertion which reaches half way up the thigh (Fig 112)

Origin The tuberosity of the ischium by a common tendon with the biceps femoris

Insertion The upper part of the medial surface of the tibia along with the sartorius The tendon of insertion of this muscle forms one of the medial hamstrings

Innervation From two branches of the tibial portion of the sciatic nerve Fibers come from the fifth lumbar and first and second sacral nerves

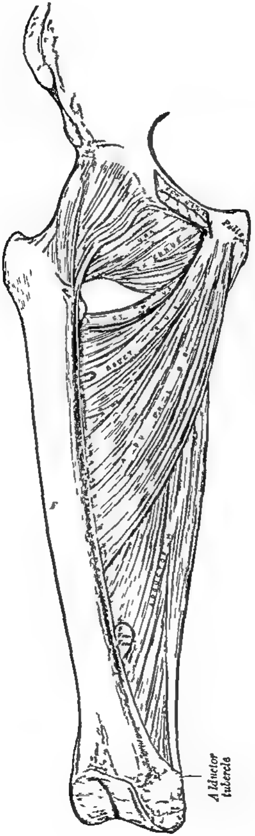

FIG 113 —Deep muscles of the medial femoral region (*Gray s Anatomy*)

GRACILIS

A slender muscle passing down the inner side of the thigh (Figs 109, 219 223)

Origin Anterior margins of the lower half of the symphysis pubis and the upper half of the pubic arch

Insertion The upper part of the medial surface of the body of the tibia below the condyle

Innervation A branch from the anterior division of the obturator nerve which contains fibers from the third and fourth lumbar nerves

Structure A thin flat tendon above with slightly converging fibers to a round tendon below

Action Adduction at the hip joint Assists with flexion and inward rotation At the knee assists with flexion and inward rotation

ADDUCTOR LONGUS

This muscle lies just to the inner side of the pectineus (Fig 109)

Origin *The front of the pubis just below the crest*

Insertion The linea aspera in the middle third of the thigh

Innervation A branch of the anterior obturator nerve which contains fibers from the third and forth lumbar nerves

Structure A thick triangular muscle arising by a short tendon and diverging fanwise to its wide insertion

Action Adduction of the hip joint Assists with flexion and outward rotation Isolated action of the adductor longus is a combination of flexion and adduction but it does not flex enough to lift the thigh over the other one while sitting as the pectineus does

ADDUCTOR BREVIS

A short triangular muscle behind and above the adductor longus (Fig 113)

Origin Outer surface of the inferior ramus of the pubis

Insertion The upper half of the linea aspera

Innervation A branch of the anterior obturator nerve which contains fibers from the third and fourth lumbar nerves

Structure A fan shaped sheet similar to the longus but shorter

Action Adduction of the hip-joint Assists with flexion and outward rotation

ADDUCTOR MAGNUS

One of the largest muscles of the body situated on the medial side of the thigh (Fig 113)

Origin The front of the pubis the tuberosity of the ischium and the whole length of the ramus connecting the two

Insertion The whole length of the linea aspera and the inner condyloid line and the adductor tubercle on the medial condyle of the femur

Innervation Branches from the posterior division of the obturator nerve which contains fibers from the third and fourth lumbar nerves and also a branch from the sciatic nerve which innervates the lower fibers

Structure The fibers from the pubis pass horizontally across to the femur

ductors are doing the main work of the movement, and so they perform incidentally the slight work of rotating the limb In throwing putting the shot batting and serving the same is true, inward rotation is done with much more power than the opposite

ACTIONS OF THE HIP FLEXORS

Because of their common tendon of insertion and similarity of action, the psoas and the iliacus are often referred to as the *ilio psoas group* Under certain conditions the psoas has complex effects upon the lumbar spine (see detailed discussion in Chapter 16 p 308) Both the psoas (indirectly) and the iliacus (directly) tend to tilt the pelvis forward if they contract when the femur is fixed as in erect weight bearing or when an attempt is made to flex the hip against heavy resistance as in the double leg lift exercise from supine lying position Thus the psoas and iliacus may play a crucial role in faulty posture Both muscles are ordinarily relatively well developed They are called into action in nearly all activities requiring forceful hip flexion, since they are the only prime movers for hip flexion which have no other prime mover actions to distract from their effectiveness

Habitually poor posture involving increased lumbar curvature and increased forward pelvic tilt often results in the development of abnormally short psoas and iliacus muscles This condition may make it impossible for an individual to flatten the lumbar spine and extend the hip simultaneously

Despite the importance of the ilio psoas group in forceful hip flexion, these muscles and the other hip flexors are usually found to be relaxed during erect standing This is possible because the trunk is inclined backward very slightly, so that the line of gravity falls just to the rear of the femoral heads The strong Y ligaments (ilio femoral bands) of the hip joint prevent the trunk from falling backward in this situation removing the need for anterior postural stabilization by the hip flexor muscles

During simultaneous knee extension and hip flexion as in kicking, the rectus femoris is an obvious mover during simultaneous knee flexion and hip flexion as in walking uphill in herringbone fashion on skis the sartorius contracts vigorously In situations such as these the ilio psoas group is important as a hip flexor

Certain special aspects of the functioning of the two joint muscles of the thigh are discussed in Chapter 14 p 253 The actions of the ilio psoas group must usually be considered in relation to these special functions of the two joint muscles Since the location and activity of the psoas and iliacus cannot be studied by palpation or observation, and since two dimensional pictures are inadequate to demonstrate the positional relationships, the beginning student should study descriptions of the attachments with unusual care and should use elastic bands or other means to simulate the origin course, and insertion on an articulated skeleton if possible

ACTIONS OF THE HIP EXTENSORS

The biceps semitendinosus and semimembranosus form a group known as the *hamstring muscles* These muscles although smaller and less powerful extensors of the hip than the gluteus maximus are much more useful for the ordinary purposes of life because they act in walking and in standing while the

much like those of the brevis, those from the ramus pass lower on the linea aspera those from the tuberosity of the ischium go to the lower end of the condyloid line

Action The whole muscle adducts the hip joint The upper fibers assist with inward rotation and flexion, the lower fibers assist with outward rotation and extension

The ability of the adductor magnus to inward rotate the hip joint is utilized in such actions as stemming in skiing and in gripping the horse s sides while riding Any strain of this muscle is colloquially termed rider s strain, although among athletes such injuries are most commonly incurred by performers on certain pieces of gymnastic apparatus [5]

THE SIX OUTWARD ROTATORS

It will be recalled that inward rotation of the arm is performed incidentally by the large muscles having the larger duty of swinging the arm and that outward rotation is performed by a special group of two muscles the infraspinatus and teres minor It is interesting to find that in the case of the hip we have a similar arrangement inward rotation being performed incidentally by the three abductors along with their main work, and outward rotation by a special group, in this case of six in place of two the piriformis obturator externus obturator internus gemellus superior, gemellus inferior, quadratus femoris (Fig 113)

Origin The posterior portions of the pelvis

Insertion The great trochanter of the femur

Innervation

Piriformis—Branches from the first and second sacral nerves

Obturator internus—A nerve from the sacral plexus containing fibers from the fifth lumbar and first and second sacral nerves

Obturator externus—A branch of obturator nerve The fibers are from the third and fourth lumbar nerves

Quadratus femoris—A nerve from the sacral plexus that contains fibers from the fourth and fifth lumbar and first sacral nerves

Gemellus superior—Same as obturator internus

Gemellus inferior—Same as quadratus femoris

Action These six muscles cannot be palpated but their position indicates that outward rotation must be their main function Electrical stimulation confirms this action It is true here, just as in the case of the arm, that forward movement of the limb through a right angle puts the group in a position to produce abduction as well as rotation it is easy to observe on a mounted skeleton that contraction of the outward rotators while sitting will separate the knees

If in walking and running the hips do not swing forward and backward there is no rotation in the hip joints but usually the hip goes forward as the foot goes forward the amount of the swing varying considerably in different individuals Now a forward swing of the hip as the limb swings forward will swing the toe in unless there is outward rotation in the hip joint It follows that in walking and running the limb must be rotated outward on the side where the large muscles are doing little calling for an extra group to do it while inward rotation must occur on the side where the extensors and ab

the person to habitual lateral curvature of the spine In healthy, active persons, such a purely functional scoliosis does not assume the danger attached to structural scoliosis caused by unilateral short leg or unilateral paralysis but the habit of standing on one foot is nevertheless to be condemned from the standpoint of postural hygiene

For normal individuals special exercises for development of the hip abductors are usually unwarranted since the natural activities of walking running skipping, hopping kicking and balancing will strengthen not only the gluteus medius but also the lateral stabilizers of the spine and other joints Sedentary adults and children who are deprived of vigorous natural activity, however may be especially susceptible to lateral spine defects

ACTIONS OF THE HIP ADDUCTORS

Paralysis of the adductors causes some difficulty in walking and running but is not nearly so serious as the loss of the flexors extensors or abductors Vigorous adduction of the hip is useful in riding horseback climbing a rope or a tree and similar activities but one may wonder what causes the development of such large masses of muscle when there is apparently so little for them to do The explanation is probably the fact that there are so many secondary actions for them to perform Each adductor has at least two other possible actions on the hip joint and some help with knee motions as well The development of the adductor muscles is justified by the tremendous variety of combinations of movements which are required for versatile functioning of the body in many activities For example, pivoting and cross over steps in football and basketball require hip flexion or extension with inward or outward rotation and adduction The adductors are needed to perform these movements even when the adduction component involves very little resistance

Kinesiological Effects on the Femur Primitive peoples do a great deal more squatting running and jumping than is true of their civilized contemporaries The muscular actions involved may result in certain structural alterations of the femur Among such alterations reported in the literature are the following The depth of the posterior end of the patellar groove is considerably greater in primitives probably due to the pressure of the posterior cruciate ligament when the limb is in the squatting position An articular facet may be found on the supero lateral margin of the patellar surface This is attributed to the action of tendon of the quadriceps femoris muscle while the joint is fully extended There is a very noticeable development of the adductor tubercle, it seems likely that this is connected with a greater development of the adductor magnus muscle which is probably used in the squatting position to stabilize the limb [6]

The head of the femur must sustain not only the pressure of the superincumbent body weight but also the force of the abductor muscles and the tension on the iliotibial tract which interact to hold the pelvis in equilibrium This force is not normally borne vertically, Rather it is transmitted to the femoral head at an angle and the plane of the resulting force is in line with the medial trabeculae of the femur The angle of this plane is approximately 165 to 170 degrees In cases of early paralysis the weakened muscles do not permit the pelvis to be held in the normal position The individual shifts his

gluteus maximus does not The consequence is that one who has lost the use of the gluteus maximum may stand and walk normally while one who has lost the hamstring muscles can stand and walk only by throwing the weight of the trunk so far back that it tends to overextend rather than to flex the hip, putting a tension on the iliofemoral band Such a position can be maintained without the use of the hamstrong group while standing still and in walking carefully on a smooth and level place, but one who has lost the hamstring group cannot walk rapidly or irregularly nor can he run, hop, jump dance or incline the trunk forward without falling

When the trunk in a normal individual is inclined forward on the hip joints as an axis, the knees being kept extended and the trunk held as straight as it is in the erect position the average adult can incline until the flexion in the hip joints is about 45 degrees the hamstring muscles somewhat shortened by contracting to sustain the weight of the trunk, permit no further flexion One can flex one hip farther than this while standing on the other foot because in this position the hamstring group is relaxed and therefore longer than in the preceding case The same is true when one sits on the floor with the legs out straight in front by using all the force of the flexors most people can hold the trunk erect the stretched and relaxed hamstring muscles permitting a flexion of 90 degrees While sitting on a chair or bench there is no difficulty in holding the trunk erect because now the hamstring muscles are not only relaxed, but further slackened at the lower end by flexion of the knee the hips will flex several degrees farther here and also in sitting on the floor if the knees are flexed, tailorwise Persons who work sitting in an automobile or at a desk may develop contractures of the hamstrings and calf muscles strong enough to produce severe chronic backaches

ACTIONS OF THE HIP ABDUCTORS

Whereas there are several assistant movers for hip abduction only one muscle is listed as a prime mover—the gluteus medius There are relatively few necessary life activities calling for a significant amount of forceful abduction of the femur away from the center line of the whole body and at first thought it may appear that development of the gluteus medius is of small importance However as pointed out in the preceding discussion of this muscle the gluteus medius performs the crucial task of stabilizing the pelvis in a more or less level position atop the femur during periods of single leg support in walking and all other forms of bipedal locomotion If the gluteus medius be paralyzed the Trendelenburg sign (lateral pelvic tilt or hip drop) occurs whenever there is unilateral support on the same side as the paralyzed muscle During this unilateral support not even momentary stabilization of the pelvis is possible therefore the paralyzed individual resorts to the characteristic *gluteus medius limp* in which the trunk is tilted laterally to the same side until the center of gravity of the body parts above the hip is directly over the femoral head The lateral waddle is very noticeable and is accentuated in bilateral fashion if both gluteus medius muscles are affected

Relaxed standing on one foot is usually accompanied by relaxation of the gluteus medius on the same side resulting in hip drop on the opposite side similar to the Trendelenburg sign If such a stance is habitually assumed the lateral ligaments of the hip and spine are stretched unilaterally predisposing

the person to habitual lateral curvature of the spine In healthy, active persons such a purely functional scoliosis does not assume the danger attached to structural scoliosis caused by unilateral short leg or unilateral paralysis, but the habit of standing on one foot is nevertheless to be condemned from the standpoint of postural hygiene

For normal individuals, special exercises for development of the hip abductors are usually unwarranted since the natural activities of walking, running skipping hopping, kicking and balancing will strengthen not only the gluteus medius but also the lateral stabilizers of the spine and other joints Sedentary adults and children who are deprived of vigorous natural activity however, may be especially susceptible to lateral spine defects

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center of gravity by bending to the affected side and the resultant forces on the femoral neck shift more nearly to the vertical In time a deformation of the neck of the femur (*coxa valga*—an increase in the angle between the neck and shaft of the femur) results Individuals with certain hip diseases may also shift their centers of gravity over the hip, thus reducing the pull of the abductor muscles and decreasing the total load on the femoral head The load is carried more vertically on the femur, giving rise to the so called "antalgic (pain relieving) gait, but this effects a change in the direction of the forces reacting on the femur The result may be bone deformation or shearing stress on the epiphyseal plate [7]

Implications for Athletic Training The violent exertion the gravitational load to be borne the extreme range of movement and the abrupt changes in direction required in athletics make the muscles of the hip joint peculiarly susceptible to injury

Powerful contraction of the quadriceps coupled with a failure of the antagonists to relax quickly enough may result in tears of the hamstrings usually the semitendinosus or semimembranosus (sprinter s strain) In certain styles of high jumping it is necessary to twist one leg and rotate the body so that a severe strain is placed on the outward rotators (high jumper s strain) Trauma to the adductor muscles may result while horseback riding or in gymnastics (rider s strain) Dancers and acrobats are said to be subject to tearing of the fibers of the adductor longus muscle near its tendinous attachment to the pubis while performing the split

Injuries of this type are often slow to heal and tend to recur There is a general belief among both athletes and dancers that they can best be prevented by slow, careful, stretching exercises before engaging in activity

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LABORATORY EXERCISES

1 Compare the pelvic girdle with the shoulder girdle of a skeleton Why do some kinesiologists insist that the pelvic girdle is properly designated but the shoulder should be referred to as a functional unit not as a girdle?

2 Palpate the gluteus maximus Is it brought into action more forcibly when the hip is flexed or when it is extended? Does it contract in normal walking? Does it contract in climbing stairs?

TABLE 10.—Hip Joint Muscles and Their Actions

	Flexion	Extension	Abduction	Adduction	Inward Rotation	Outward Rotation
Psoas	PM					
Iliacus	PM					
Sartorius	Asst		Asst			Asst
Rectus femoris	PM		Asst			
Pectineus	PM			PM		Asst
Tensor fasciae latae	Asst		Asst		PM	
Gluteus maximus		PM	Asst *	Asst **		PM
Biceps femoris (long head)		PM				Asst
Semitendinosus		PM			Asst	
Semimembranosus		PM			Asst	
Gluteus medius	Asst †	Asst ††	PM		Asst †	Asst ††
Gluteus minimus	Asst †	Asst ††	Asst		PM†	Asst ††
Gracilis	Asst			PM	Asst	
Adductor longus	Asst			PM		Asst
Adductor brevis	Asst			PM		Asst
Adductor magnus	Asst *	Asst **		PM	Asst *	Asst **
The six outward rotators						PM

* Upper fibers
** Lower fibers
† Anterior fibers
†† Posterior fibers

3. In what respects is the biceps femoris similar to the biceps brachii? In what respects does it differ?

4. Which bones are the most useful to physical anthropologists and detectives in determining stature from skeletal material? (Suggestion: See Mildred Trotter and Goldine C. Gleser, "A Re-Evaluation of Estimation of Stature Based on Measurements of Stature Taken During Life and Long Bones After Death," Am. J. Phys. Anthropol., *16* N.S.: 79–123, 1958.)

5. What are the best progressive resistance exercises to develop the muscles of the pelvic girdle?

6. Assume that one individual does deep knee bends (heels raised from the floor) and that another does squats (heels on the floor). What will be the difference in the effect on muscular development of the thighs?

7. In the October 13, 1958 issue of *Time* it was reported that a Washington doctor had treated 25 patients for back injuries suffered while trying hula hoops. Analyze the movements of the pelvic girdle and determine the points of greatest strain. (Suggestion: See "The Anatomy of Hula Hooping," Scope Weekly, *3*: October 8, 1958, and "Hula-hoop Syndrome," Brit. Med. J., *5111*: 1531, 1958.)

Chapter 14

Movements of the Knee Joint

THE knee the largest and most complex joint in the body, has probably evolved from three separate joints In man there is a single joint cavity, but three separate articulations may be identified between the medial condyles of the femur and tibia between lateral condyles of the femur and tibia and between patella and femur Figures 114 through 120 illustrate the structures which are described below

At the distal end of the femur, the following bony landmarks are important The *medial* and *lateral condyles* each provided with *epicondyles* bear articular surfaces for contact with the tibia and its cartilages Anteriorly, the condyles are separated by the shallow depression of the articular *patellar surface* and posteriorly and inferiorly by the deeper *intercondyloid fossa* (Fig 108)

At the proximal end of the tibia the following bony landmarks are important The *medial* and *lateral condyles* are indistinctly separated except on the superior surface where the *anterior* and *posterior intercondyloid fossae* and the *intercondyloid eminence* occur between the two facets of the *superior articular surface* Approximately one half inch from the proximal end the tibial *tuberosity* projects anteriorly Laterally the *head of the fibula* forms the *proximal tibio fibular articulation* with the lateral condyle of the tibia Although this joint is separate from the knee joint the head of the fibula has some functional relationships with the workings of the knee joint

The *patella* or knee cap is a sesamoid bone (develops intramembranously) within the tendon of the quadriceps femoris muscle group The patella is roughly triangular with its apex projecting inferiorly and serving as the *proximal attachment for the patellar ligament which proceeds inferiorly to its* distal attachment on the tuberosity of the tibia Technically the patellar ligament is appropriately named since it joins bone to bone but functionally it is a tendon being composed of fibers which are continuous with those of the quadriceps tendon The posterior surface of the patella bears facets for articulation with the patellar surface of the femur The patella protects the anterior aspect of the knee joint and acts as a sort of pulley by increasing the

angle of insertion of the patellar ligament upon the tibial tuberosity, thus improving the mechanical advantage of the quadriceps femoris muscle group

On the superior articular surfaces of the tibia are the *medial* and *lateral menisci*, or *semilunar cartilages* composed of tough fibro cartilage The cartilages serve to adapt the shapes of the femoral condyles to the articular surface of the tibia to buffer the jars of walking and jumping to prevent fric

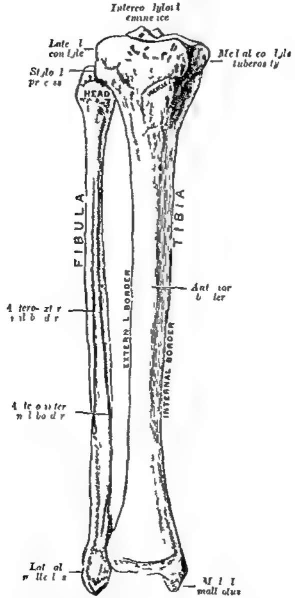

FIG 114 —The right tibia and fibula front view

tional wear, and by deformation to allow the motions of the knee joint The menisci are roughly crescentic in shape the lateral meniscus being smaller in circumference than the medial meniscus Each is somewhat triangular in cross section being much thicker at the peripheral border The anterior ends of each meniscus are attached to the anterior intercondyloid fossa of the tibia and to each other by a *transverse ligament* which is sometimes absent

The posterior ends are attached to the posterior intercondyloid fossa The peripheral borders of each meniscus are attached to the edges of the tibial condyles by *coronary ligaments* with vertical fibers the inner borders of the menisci are free, as are the superior and inferior surfaces The medial meniscus is attached at its periphery to the tibial collateral ligament, the lateral meniscus has no such attachment to the fibular collateral ligament, but its posterior end gives off the *ligament of Wrisberg* to the medial condyle of the femur just behind the posterior cruciate ligament These anatomical details are important to the understanding of knee injuries which will be considered later in this chapter

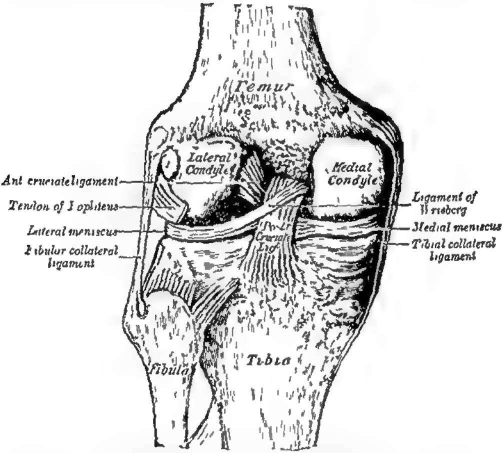

FIG 115 —Posterior aspect of left knee joint showing interior ligaments (*Gray's Anatomy*)

The strong *anterior* and *posterior cruciate ligaments* are the main structures forming the incomplete *intercondylar septum* which partially divides the knee joint cavity into right and left halves The anterior cruciate runs from the anterior intercondyloid fossa of the tibia upward and backward to the inter condyloid fossa of the femur the posterior runs from the posterior inter condyloid fossa of the tibia upward and forward to the intercondyloid fossa of the femur

The *tibial collateral ligament* on the medial side of the knee joins the medial

condyles of the femur and tibia, merging on the way with the capsule of the joint and with the coronary ligament of the medial meniscus The *fibular collateral ligament*, on the lateral side of the knee, joins the lateral condyle of the femur with the head of the fibula The tendon of the popliteus muscle separates the fibular collateral ligament from the lateral meniscus and from the joint capsule proper

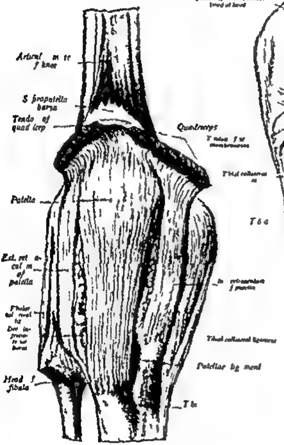

Fig 116

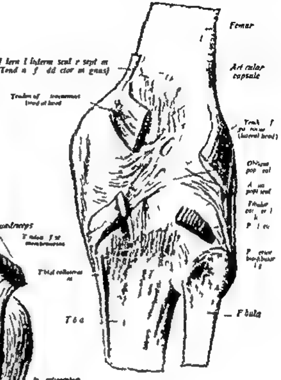

Fig 117

Anterior and posterior views of knee joints showing accessory ligaments (Sobotta)

On the posterior aspect of the knee joint the *oblique popliteal ligament* connects the articular margins of the femur and tibia and the *arcuate popliteal ligament* runs downward from the lateral condyle of the femur to the posterior surface of the joint capsule and, by two converging bands to the head of the fibula

All of the articular surfaces of the femur, tibia and patella are covered with the usual hyaline cartilage The ligamentous *joint capsule* is irregular and ex

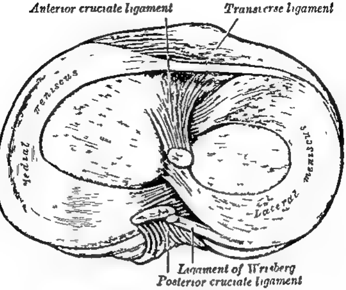

FIG 118 —Head of right tibia from above showing menisci and attachments of ligaments (*Gray s Anatomy*)

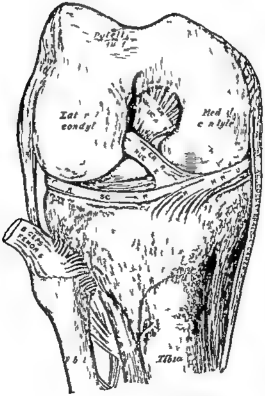

FIG 119 —Anterior aspect of right knee joint showing interior ligaments (*Gray s Anatomy*)

tensive The capsule is lined with a *synovial membrane*, which invests both the upper and lower surfaces of the two menisci, excluding them from the joint cavity

Numerous bursae occur around the joint, some of them having connections with the main joint cavity in some or all individuals The *pre patellar bursa*

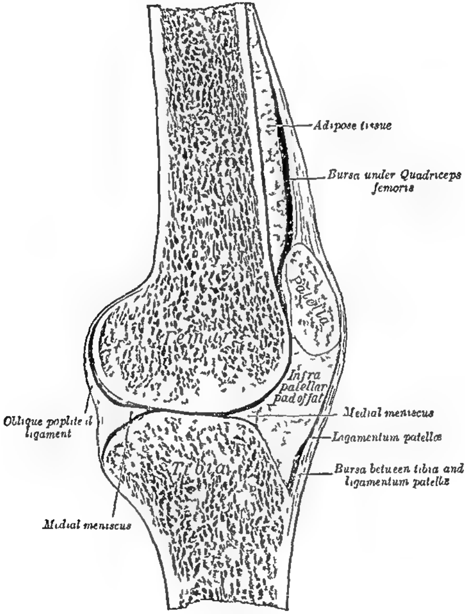

Fig 120 —Sagittal section of right knee joint (*Gray s Anatomy*)

lies between the patella and the skin on the anterior aspect The *supra patellar bursa* lies deep to the quadriceps tendon The *infra patellar bursa* lies deep to the patellar ligament and superficial to the *infra patellar fat pad* Another bursa lies subcutaneously over the tuberosity of the tibia several others

cushion the tendons of the popliteus, of both heads of the gastrocnemius, and of other two joint muscles

The fascia surrounding the knee joint merges with ligaments and when various muscles are tense, plays no small part in the stabilization of the joint Tendons of the two joint muscles (rectus femoris, the hamstrings, sartorius gracilis, and gastrocnemius) participate vigorously in strengthening and protecting the joint against unnatural or excessive movements

In the erect standing position, the tibia are almost exactly vertical, and the medial and lateral condylar articulating surfaces of both tibia and femur lie in a horizontal plane The shafts of the femur are not vertical, since the knees are relatively close together while the femoral heads and trochanters are markedly spread apart This obliquity of the shaft of the femur differs from person to person, depending upon heredity, sex (females have broader hips *in proportion to height*), nutrition and disease (especially during the growth period) occupational and recreational activity muscular development, foot gear and other factors Torsion in the shaft of the femur and angle between shaft and neck of the femur also vary These differences may affect gait and other functions and are important considerations in orthopedic medical practice and therapeutic programs

There are twelve muscles acting on the knee joint These may be divided into three groups

Hamstring group Semitendinosus semimembranosus biceps femoris

Quadriceps femoris group Rectus femoris vastus lateralis, vastus intermedius vastus medialis

Unclassified group Sartorius gracilis, popliteus gastrocnemius plantaris

Some of these have been discussed earlier, one (plantaris) will be described in the next chapter

POPLITEUS

Origin The lateral aspect of the lateral condyle of the femur (Fig 117)

Insertion Medial posterior side of tibia superior to the origin of the soleus

Innervation A branch of the tibial nerve which contains fibers from the fourth and fifth lumbar and first sacral nerves

Structure A thin, flat, triangular muscle which forms the lower part of the floor of the popliteal space

Action Flexion and medial rotation of the tibia Aids in unlocking the knee at the start of knee flexion Assists in stabilizing the knee in the crouching position [1]

VASTUS LATERALIS

A large muscle located half way down the outer side of the thigh and making the rounded eminence to be found there It corresponds closely to the lateral head of the triceps brachii (Figs 109, 121)

Origin The lateral surface of the femur just below the greater trochanter and the upper half of the linea aspera (Figs 221 222)

Insertion The lateral and superior borders of the patella and the quadriceps femoris tendon

Innervation Branches from the femoral nerve which contain fibers from the second, third and fourth lumbar nerves

Structure A small portion of the muscular fibers arises directly from the femur near the trochanter the greater part arises from a tendon shaped much like a sheet of paper covering the outer surface of the muscle for its upper two thirds with its posterior edge attached to the linea aspera The lower

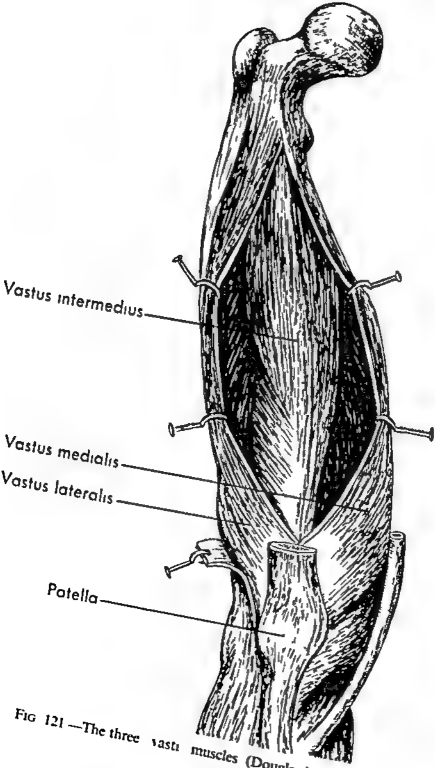

FIG 121 —The three vasti muscles (Douglas)

tendon is a flat sheet attached to the upper border of the patella and serving as a tendon of insertion for the three vasti muscles it lies beneath the vastus lateralis and the muscle fibers pass obliquely downward and inward from the upper tendon to join it

Action Prime mover for knee extension It needs a companion from the inner side to give a straight pull on the patella

VASTUS MEDIALIS

This muscle, corresponding to the medial head of the triceps brachii is located on the medial side of the thigh somewhat lower than the lateralis and partly covered by the rectus and the sartorius (Figs 109 and 121)

Origin The whole length of the linea aspera and the medial supracondylar line (Figs 108 221, 222)

Insertion The medial border of the patella and the quadriceps femoris tendon

Innervation Branches from the femoral nerve which contain fibers from the second, third and fourth lumbar nerves

Structure Similar to the vastus lateralis

Action Prime mover for knee extension Its diagonal pull inward counter balances the vastus lateralis diagonal pull outward and the two muscles give a straight pull on the patella Since this muscle is mainly responsible for the last few degrees of knee extension it is particularly important in the function ing of the screw home movement of the knee joint

The line of pull is similar to that of the externus except that it is directed diagonally inward instead of outward Isolated action causes inward displace ment of the patella paralysis makes the patella liable to outward displacement

VASTUS INTERMEDIUS

A companion of the two preceding muscles lying between them and be neath the rectus femoris (Fig 121) It is difficult to separate this muscle from the medialis and the two may be continuous for part of their length

Origin Anterior and lateral aspect of the femur except the inferior 4 inches

Insertion The superior border of the patella via the quadriceps femoris tendon

Innervation Branches from the femoral nerve which contain fibers from the second third and fourth lumbar nerves

Structure The muscle fibers arise directly from the bone and pass down ward and forward to join the deeper surface of the sheet which serves as a tendon for the two preceding muscles

Action Prime mover for knee extension Like the rectus femoris its pull is directly upward on the patella

ILIOTIBIAL BAND

The iliotibial band or iliotibial tract is a broad ligament connecting the ilium with the lateral tubercle of the tibia the patella the linea aspera and the lateral condyle of the femur The tensor fasciae latae inserts into it and the band itself inserts into the tibia and blends with fibrous expansions from the vastus lateralis and biceps femoris This tract has been found only in man

other animals have developed the tensor fasciae latae without simultaneously developing the iliotibial band The tension of this tract strongly reinforces the lateral retention apparatus of the knee joint and thus contributes importantly to the maintenance of erect posture However, in cases of pathological contractures such as may follow poliomyelitis it may produce severe deformities involving the hip and the knee joints [2]

MOVEMENTS OF THE KNEE JOINT

Flexion and Extension The fundamental movements of the knee joint are *flexion* and *extension* but the knee is not a simple ginglymus or hinge joint With the knee fully extended the femoral condyles project posteriorly from the line of the shaft of the femur As the knee is flexed the femoral condyles would tend to roll like wheels off the posterior edge of the tibia if they were not restrained by the cruciate ligaments the fascia lata and other fascial and muscular structures As flexion progresses the anterior cruciate ligament becomes taut and forces the femoral condyles to slide forward on the menisci Thus there is the tendency for approximately the same spot on the tibia to make contact with progressively more posterior parts of the condyles of the femur From a position of full flexion as extension occurs there would be a tendency for the femur to roll off the anterior edge of the tibia if the posterior cruciate ligament did not become taut and force the femoral condyles to slide backward on the menisci

Flexion of the knee is possible through about 135 degrees when it is brought to a stop by contact of the tissues on the back of the thigh and leg and by the capsular and cruciate ligaments Maximum strength in the leg lift is developed when the lift is done with the thighs and legs making an angle at the knees of from 115 to 124 degrees Since the angle has a decided effect on scores it is possible to compare leg lift figures only if they are recorded with the knee flexed to a specified degree [3]

The Normal Locking of the Knee The joint can be very slightly hyperextended Further hyperextension is limited by the anterior cruciate ligament, and perhaps also by parts of the fascia lata collateral ligaments and other connective tissues When the body is balanced in an erect position the gravity line falls slightly in front of the tibio femoral articular contact points Thus the quadriceps extensor muscles can relax because the knees are effectively locked in hyperextension by the small gravitational torque

Locking of the knees is not a simple hyperextension however In the last phase of the movement there is a small amount of inward rotation of the femur on the tibia This final seating of the femoral condyles into the contours of the menisci is sometimes called the screw home movement of the knee Without this axial rotation of the femur, locking of the knee joint is incomplete

Grant[4] has stated that no special rotator muscles are necessary the screw home movement being produced by the continued contraction of the quadriceps extensor muscles against the resistance of the anterior cruciate ligament and by the impingement of the anterior border of the medial meniscus against the medial groove on the articular surface of the medial femoral condyle However some clinicians contend that the action of the vastus medialis which carries the lower leg through the last 15 degrees of extension is essen

tial to this movement, since rehabilitation of that muscle requires forceful locking of the knee against resistance in addition to exercise in the intermediate ranges of joint action

While bearing weight on the extremity, muscular action is necessary to reverse the screw home movement as the knee is unlocked in the first stage of flexion The popliteus is the muscle which provides the motive force for the unlocking The popliteus is listed as a prime mover for inward rotation of the knee, the assumption being that the tibia is the moving part While bearing weight in a position of complete extension however the tibia cannot rotate therefore, the femur is rotated outward slightly as the result of contraction of the popliteus effectively reversing the screw home movement When weight is not being borne on the extremity, the unlocking can occur passively as a by product of knee flexion

Why is the screw home movement necessary? The answer is found by close study of the shapes and contours of the articulating parts The medial and lateral articulating surfaces of the tibia are not bilaterally symmetrical neither

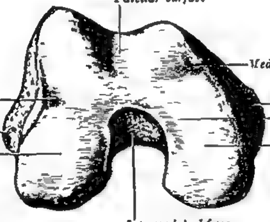

FIG 122 —Lower extremity of right femur viewed from below (*Gray s Anatomy*)

are the medial and lateral articulating surfaces of the femur Figure 118 shows that the antero posterior diameter of the cup formed by the medial meniscus is greater than that formed by the lateral meniscus and there are differences in shape Furthermore the lateral meniscus is more mobile during knee extension being able to slide forward because its edge is not attached to the collateral ligament as is the edge of the medial meniscus Figure 122 shows that the antero posterior dimension of the tibial surface of the medial condyle of the femur is greater than that of the lateral condyle of the femur (The tibial surfaces should not be confused with the patellar surface) These and other topographical differences require some axial rotation (screw home movement) in the femur if the parts are to fit together neatly when knee extension is completed

Rotation When the knee is locked in extension no rotation is possible although the foot may still be turned inward and outward by rotation at the ankle and hip joints As the knee is flexed the collateral ligaments and fascia

become progressively more slack, permitting *inward* and *outward rotation* After about 90 degrees of flexion, as much as 60 to 90 degrees of rotation may be possible In the extended knee postural stability is encouraged by the lack of rotation but the joint is very vulnerable to injury from lateral forces During activity when the knee is likely to be flexed to some extent the ability to rotate makes possible a wide variety of movements such as pivoting changing direction of locomotion grasping objects between the soles (as in climbing a pole), and performing inside and outside ankle kicks in soccer

ACTIONS OF TWO JOINT MUSCLES

The preceding analysis has shown that certain muscles act simultaneously on both the hip joint and the knee joint The nerve endings in dogs suggest that one part of a two joint muscle may shorten while another lengthens,[5] but so far this phenomenon has not been demonstrated to occur in man under normal conditions [6] It seems safe to assume that in the latter when a two joint muscle contracts it pulls at both ends at once For example the sartorius flexes both the hip and the knee in withdrawing the foot from a painful stimulus in initiating the forward swing of the lower limb just after the vigorous push off of a crouch start in running and in stepping up onto a high bench Similarly the rectus femoris both flexes the hip and extends the knee in punting a football

However, the action of the two joint muscles of the hip and knee is not as simple as these examples might indicate and the study of the functions of individual muscles is insufficient to account for all of the observed phenomena of lower limb movement During normal body motions, muscles tend to act in groups and to effect a coordinated movement The composition of a group is not constant The muscle members are selected according to the needs of the teamwork which is desired Analogously it might be compared to a coach (the central nervous system) drawing on his past experience (conditioned reflexes) to send into the game (cause to contract) various combinations of his players (muscles) according to the different game situations such as general offense (hip flexion and knee extension) defense against running attack (hip and knee flexion) or defense against passing attack (hip and knee extension) The teamwork of muscles is complex even when it involves one joint muscles only If two joint muscles are involved the complexity is greatly increased and a special analysis must be made

Lombard's Paradox While sitting in a chair, the student may grasp his thigh so that the thumb palpates the belly of the rectus femoris and the fingers palpate the bellies of the hamstrong muscles As he arises from the chair by means of hip and knee extension he will feel both the rectus femoris and the hamstring muscles spring into action It may surprise him to find that all of these muscles are active since he will recall that while the rectus femoris tends to extend the knee it also tends to flex the hip and while the hamstrings tend to extend the hip, they also tend to flex the knee He might expect that the rectus femoris and the hamstrings would mutually neutralize each other s action at both the hip and knee joints This seemingly contradictory situation is known as Lombard s Paradox after W P Lombard [7] who was one of the first scholars to analyze and clearly explain the problem

Study of the action of the two joint muscles of the thigh during simultaneous hip and knee extension may be approached step by step through the use of the simple model shown in Figure 123A and B. Figure 123A shows an elastic band placed so as to represent a hamstring muscle. If the elastic band is placed on the opposite side of the model, it represents the rectus femoris muscle. Now if two elastic bands are employed, simulating simultaneous contraction of the hamstrings and the rectus femoris, as shown in Figure 123B, the paradox appears. Extension takes place at both joints! Lombard's explanation, which is still accepted, in spite of alternative proposals, is based on anatomical measurements which have been deliberately duplicated in the

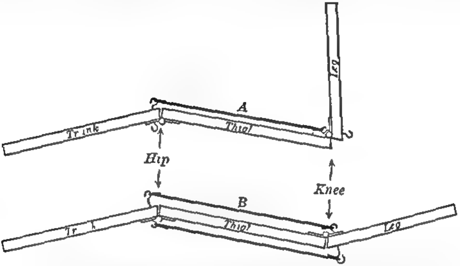

FIG. 123.—Lombard's Paradox. *A*, hamstring extending hip and flexing knee. *B*, hamstring with aid of tendon action of rectus femoris, extending both joints.

model. At the hip joint the lever arm (that is, the distance from the center of rotation of the joint to the point of attachment of the muscle) of the hamstrings for extension is greater than that of the rectus femoris for flexion. The rotational torque for each muscle is equal to the force of its pull multiplied by its perpendicular distance from the axis of rotation. Assuming that the forces developed within the two muscles are equal, the torque of the hamstrings for hip extension is greater than the torque of the rectus femoris for hip flexion because of the difference in lengths of the lever arms. A similar but opposite situation exists at the knee joint. The torque of the rectus femoris for knee extension is greater than the torque of the hamstrings for flexion. Elftman[8] has presented the lengths of these lever arms in a representative individual, as shown in Table 11. These figures are here cited out of context.

TABLE 11.—Comparative Lengths of Lever Arms of Two Joint Muscles

	LENGTH OF LEVER ARMS	
	At Hip Joint	*At Knee Joint*
Rectus femoris	3.9 cm	4.4 cm
Hamstrings	6.7 cm	3.4 cm

and should be interpreted only as rough approximations for comparative purposes

In summary, it may be said that Lombard s Paradox is explained by the fact that the leverages of the bones comprising the joints prevent the funda mental antagonism of the muscles from completely neutralizing each other s actions

Tendinous or Belt-Like Action of Two-Joint Muscles The model in Figure 123 may be further utilized to illustrate another principle of two joint muscle action If either one of the elastic bands is replaced with a taut cord the work-ing of the model is not altered Extension at both joints still results The action of the model in this instance may be explained by what is variously called the *tendinous action belt like action* or *pulley action* of the two joint muscles Let us assume that the hamstrings are represented by the elastic band and the rectus femoris by the cord The tension within the elastic band (simulating contraction of the hamstrings) pulls the hip into extension This movement causes a pull on the cord (rectus femoris) which is transmitted to the other end of the cord causing extension of the knee just as if a contracting muscle were operating Extension of the knee would of course be opposed by the tension within the elastic band but at each joint the long lever arms for extension determine the movement which takes place In this situation, the passive function of the cord in transmitting the tension is similar to the function of a rectus femoris muscle whose connective tissue will not allow it to be stretched more than a certain amount thus making it tight even though it is relaxed

If *both* elastic bands on the model are replaced by taut cords it is virtually impossible to tie them tight enough to introduce tension into the closed sys tem Hence the model no longer exhibits extension at both joints but lies motionless in whatever position it is placed However the cords are suffi ciently tight to compare with relaxed hamstring muscles which are also notoriously taut in living individuals Now if the model is grasped by the trunk member with one hand and if the other hand is used to flex the thigh on the trunk the leg will also flex on the thigh The cords now act like an endless belt going around pulleys at the hip and knee joints Hip flexion causes a pull on the hamstrings which is transferred to the knee joint, flexing it Knee flexion causes a pull on the rectus femoris which is transferred to the hip joint furthering the flexion which was originally induced by the outside force Under similar circumstances, if the model is manipulated so as to extend the hip then the knee is also extended This same sort of tendinous action occurs in the intact human organism provided that the muscles are naturally taut or that they are contracting enough to take up slack It should be noted that the principle of tendinous action is different from and independent of the principle of differential leverage which was used to explain Lombard s Paradox The two principles may be invoked simultaneously but tendinous action would occur even if the lever arms were all of the same length

A more nearly complete and realistic illustration of tendinous action of two joint muscles in conjunction with action of one joint muscles can be achieved with the slightly more complex model illustrated in Figure 124A and B Figure 124A shows hip flexion caused by contraction of the psoas The

rectus femoris is slackened allowing the natural tightness of the hamstrings to flex the simulated knee by tendinous action The knee flexion allows the gastrocnemius to go slack, which in turn permits a minimal contraction of the tibialis anterior to dorsiflex the ankle *

If while the three joints are in a position of flexion, the gluteus maximus contracts the result is that shown in Figure 124B The gluteus maximus initiates hip extension thus removing tension from the hamstrings while

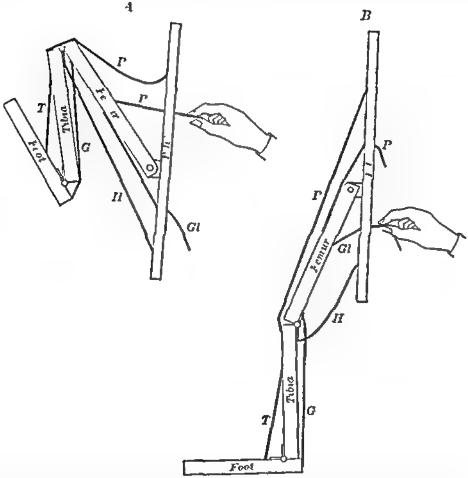

Fig 124 —The so called tendinous action of the two joint muscles of the thigh *R*, rectus femoris *P* psoas *Gl*, gluteus maximus *H* hamstring *T* anterior tibial *G* gastrocnemius (Lombard)

stretching the rectus femoris This results in knee extension which in turn takes up the slack in the gastrocnemius causing plantar flexion at the ankle

The results of manipulating models should not be over generalized Although in most people the hamstring muscles are sufficiently tight to exert

* In the frog the tibialis anterior is a two-joint muscle extending above the knee Such an arrangement allows tendinous action to encourage dorsiflexion in the situation described above In the opposite situation when multi joint extension is taking place during jumping two joint muscles enhance the activity providing kinesiologists with an extra erudite insight into Mark Twain s story of the jumping frogs of Calaveras County It may be assumed that winning jumpers have exceptionally long lever arms for extension

tendinous action at the slightest provocation, the majority of the other muscles are not Tendinous action is minimized or disappears when the two joint muscles are relaxed although it will operate whenever these muscles are contracted sufficiently to make them taut An understanding of Lombard s Paradox and the concept of tendinous action engenders appreciation of the teamwork potentiality and the versatility of the muscular system The anatomical arrangements are beautifully designed to enhance the performance of natural activities, and are especially efficient in combating the pull of gravity which constantly threatens man s upright position

Energy-conservation by Two joint Muscles One joint muscles are necessary in order to provide individuation of movement—that is, the performance of a single joint action separately from any other joint action However, a two joint muscle is much more efficient when some definite combination of actions at two different joints simultaneously is required Elftman [9] in a thorough determination of total and segmental energy exchange during running, found a stage in the forward swing of the leg shortly before it contacted the ground, in which hip extensors were required to do positive work at the same time that knee flexors were required to decelerate the extension of the knee At this moment the hamstring muscles receive kinetic energy from the momentum of the lower leg at the knee joint at the same time they are expending energy at the hip joint One joint muscles could perform the task, but the energy received at the knee joint would be wasted (dissipated as heat), whereas two joint muscles can apply at the hip joint the energy received at the knee Quantitatively the saving effected by using two joint muscles was at the rate of 1 36 horsepower which is significant in view of the fact that the total work of the limb muscles was at the rate of 2 61 horsepower

Kinesiological Effects on the Tibia In primitive people who do a great deal of running and leaping the tibia tends to become flattened in order to provide a larger surface of origin for the tibialis anterior This results from the conditions causing hypertrophy of that muscle The same conditions may be responsible for a prominence on the anterior aspect of the lateral condyle where the anterior portion of the ilio tibial tract attaches *Retroversion* is a condition in which the diaphysis is straight but the proximal end is tilted slightly backwards so that a pronounced concavity of the bone results This is found mainly in mountaineers and may result from their habit of walking with the knees slightly flexed it may also result from the act of squatting In squatting the lateral meniscus moves somewhat backwards This movement is facilitated by an increased convexity of the articular surface of the lateral condyle Such convexity has been found to be much greater in savage races than in Europeans In Europeans the anterior margin of the distal epiphysis is usually sharp but in primitives it has an articular facet toward the fibular side This fits together with a similar facet which is found on the neck of the talus It is believed to be due to the extreme dorsiflexion of the ankle joint which occurs in squatting Variations in the shape of the medial condyle also result from squatting Torsion of the tibia may result from the habit of turning the foot laterally to improve the base of support when standing The angle of torsion is about 19 degrees in modern Europeans but is less in races which rest in the kneeling position with the feet turned medially under the buttocks so that the toes point towards each other [10]

rectus femoris is slackened allowing the natural tightness of the hamstrings to flex the simulated knee by tendinous action The knee flexion allows the gastrocnemius to go slack which in turn permits a minimal contraction of the tibialis anterior to dorsiflex the ankle *

If, while the three joints are in a position of flexion, the gluteus maximus contracts the result is that shown in Figure 124B The gluteus maximus initiates hip extension thus removing tension from the hamstrings while

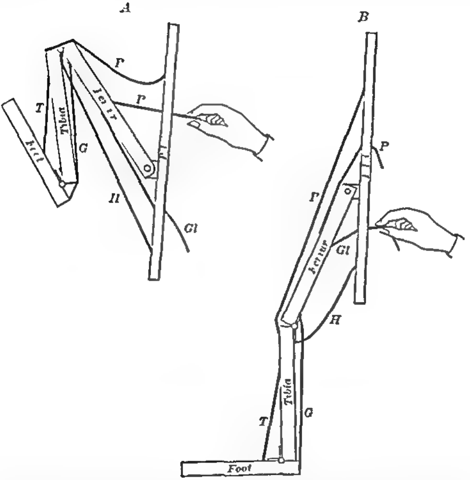

FIG 124 —The so-called tendinous action of the two joint muscles of the thigh *R* rectus femoris *P* psoas *Gl* gluteus maximus *H*, hamstring *T* anterior tibial *G* gastrocnemius (Lombard)

stretching the rectus femoris This results in knee extension which in turn takes up the slack in the gastrocnemius causing plantar flexion at the ankle

The results of manipulating models should not be over generalized Although in most people the hamstring muscles are sufficiently tight to exert

* In the frog the tibialis anterior is a two-joint muscle extending above the knee Such an arrangement allows tendinous action to encourage dorsiflexion in the situation described above In the opposite situation when multi joint extension is taking place during jumping two-joint muscles enhance the activity providing kinesiologists with an extra erudite insight into Mark Twain s story of the jumping frogs of Calaveras County It may be assumed that winning jumpers have exceptionally long lever arms for extension

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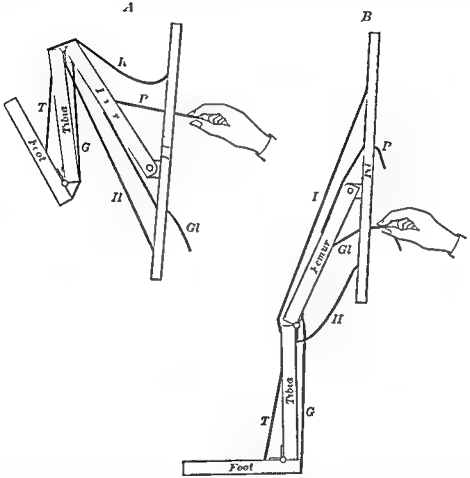

FIG 124 —The so-called tendinous action of the two joint muscles of the thigh *R* rectus femoris *P* psoas *Gl* gluteus maximus *H* hamstring *T*, anterior tibial *G* gastrocnemius (Lombard)

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the extent required, since the oblique posterior ligament and the contraction of the hamstrings may pull the femur downward and thus extend the knee Lifting of the heel produces an apparently more active extension of the knee, but the action may be performed by hip flexion In the sitting position dorsi flexion of the foot may transmit a pull to the gastrocnemius and plantaris muscles Working with reversed origins, these may pull the femur backward In leg raising from the sitting position fixation and stabilization of the knee joint may be partially accomplished by the gastrocnemius and plantaris working eccentrically with reversed origins These movements can be excluded by raising the thigh with a sandbag and thus increasing the degree of flexion at

FIG 126—Kono snatching in the squat style (Hasse courtesy *Strength and Health*) For a mechanical analysis of these two styles see Arnold Scott Arsenault *A Mechanical Analysis of the Two Weight Lifting Methods of Two Hands Snatching* Unpublished Master s Thesis Springfield College August 1957

the knee joint to such an extent that only a more forceful contraction of the quadriceps will raise the leg from its support This will also eliminate the possibility of leg raising by hip flexion

Implications for Athletic Training Ligamentous injuries of the knee joint are relatively common in body contact athletics and are frequently permanently incapacitating The lateral stability of the knee joint is maintained by the muscles and five other structures both collateral ligaments both cruciate ligaments and the articular capsule Anterior and posterior movement at the joint results when either of the cruciates is ruptured an abnormal amount of

Muscle Substitution It is the experience of every therapist that unless a patient is closely supervised during the process of rehabilitation he will tend to substitute other muscle groups for those which he finds inefficient or painful to use[11] While these so-called "trick movements" may be annoying to the therapist, they are very instructive to the kinesiologist "Trick movements" in the use of the knee extensors have been analyzed by Hill[12] He points out that

FIG 125—Use of the legs in lifting heavy weights overhead Tommy Kono, Olympic and World Light Heavyweight Weight Lifting Champion in starting position for the two hands snatch (Hasse courtesy *Strength and Health*)

treatment of any condition affecting the knee joint will include quadriceps exercises "Trick movements" enable the patient to achieve knee extension without placing a proportionate share of the work on these muscles When the patient lies supine the knee is not fully extended owing to the calcaneus and the posterior muscles being in contact with the surface upon which he is lying Static muscle contractions do not necessarily work the quadriceps to

are particularly susceptible to injury Therefore, some football coaches advise players to flex the knee and remove weight from the extremity whenever lateral impact is anticipated

Clinical reports indicate that the medial meniscus is injured much more frequently than the lateral Since the medial meniscus is attached to the tibial collateral ligament, a tearing of that collateral ligament may pull the meniscus out of place or break it The lateral meniscus does not attach to the fibular collateral ligament, furthermore, the ligament of Wrisberg (Fig 118) may provide extra stabilization

During the prolonged immobilization of the knee joint associated with rehabilitation, ankylosis* may appear This is often progressive and irreversible in nature Within twenty four hours after injury to the knee, disuse atrophy, wasting of the thigh muscles, and a loss of coordination between the muscle groups involved may be notable This is possibly due to a reflex mechanism which seeks to protect the articular synovial membrane[16] A disproportionate atrophy of the vastus medialis, which serves to carry the leg through the last 15 degrees of extension, is a familiar clinical picture[17] Once a knee has become stiffened restoration of strength to the vastus medialis in particular and of mobility to the knee joint in general presents one of the most difficult problems in physical medicine and rehabilitation Current practice holds that the first step in both the prevention and treatment of knee injuries is the development of quadriceps strength Excellent results in the treatment of various kinds of traumata to the knee have resulted from programs of progressive resistance exercise[18]

Another common and distressing athletic injury is the syndrome colloquially termed shin splints The etiology of this condition is a matter of debate In the United States they are generally considered to result from a tearing of the interosseus membrane lying between the tibia and the fibula and of the periosteum to which it is attached (irritative myositis) or a tearing of the origin of the tibialis anterior and/or tibialis anticus Some British physicians have suggested that they are the result of stress fractures of the bones During strenuous exertion contraction of the powerful plantar and long toe flexors draws the fibula toward the tibia The resultant to and fro movement is believed to cause fractures which most frequently occur near the inferior tibiofibular joint[19] They have also suggested that strong calf muscles working at their maximum strength may cause the tibia to bow forward[20] It is possible that the tibial fractures which Burrows[21] observed in male ballet dancers are injuries of a similar nature, although a different mechanism appears to be involved In any case cessation of activity seems to be the only method of rehabilitation If the athlete persists in training a long period of disability may ensue

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* Ankylosis is the knitting together of two bones resulting in a stiff joint

rotation becomes evident when the collateral ligaments are torn Collateral ligament injuries may have associated cruciate ligament injuries, and the menisci may or may not be involved[13] The medial collateral ligaments are damaged more frequently than are the cruciates and lateral collaterals[14] Most serious injuries to the knee joint can be remedied only by surgery

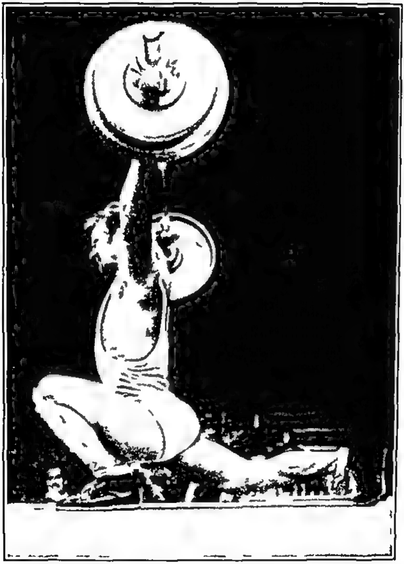

FIG 127 —Norbert Schemansky Olympic and World Middle Heavyweight Weight Lifting Champion snatching in the split style (Kirkley)

Role of Wrisberg Ligament Meniscus injuries (football knees) are com mon A meniscus may be split or cracked broken into two or more pieces or loosened by a tearing of its ligamentous attachments Such injuries usually result from a lateral blow (the result of blocking or tackling) or from in ad vertent lateral flexion (the result of turning an ankle, stepping in a hole or running on an irregular surface) When the knee is in a completely extended or nearly extended position while weight is borne on the extremity, the menisci

FIG 128 —Remarkable separation of the anterior thigh muscles displayed by Robert Walker The student will find identifying each of these muscles and their action an excellent aid to learning (Hasse courtesy *Strength and Health*)

TABLE 12 —Knee Joint Muscles and Their Actions

Muscle	*Flexion*	*Extension*	*Inward Rotation*	*Outward Rotation*
Semitendinosus	P M		P M	
Semimembranosus	P M		P M	
Biceps femoris	P M			P M
Rectus femoris		P M		
Vastus lateralis		P M		
Vastus intermedius		P M		
Vastus medialis*		P M		
Sartorius	Asst		Asst	
Gracilis	Asst		Asst	
Popliteus**	Asst		P M	
Gastrocnemius	Asst			
Plantaris	Asst			

* Responsible for the final screw home movement in knee extension
** Unlocks the knee at the start of knee flexion

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LABORATORY EXERCISES

1 It has been concluded that an important predisposing cause of falls in the aged is weakness of the quadriceps femoris (Trevor H Howell Analysis of Falls in Old People J Am Geriatrics Soc *6* 522-525 1958) Why is strength in this muscle especially important in the prevention of falls?

2 Assume that one man does deep knee bends or squats with a bar bell while another does leg presses What differences in muscular development might result? Justify your answer

3 What differences might be expected in the muscular development resulting from deep knee bends or squats and leg presses as compared with extensions of the knee done in the sitting position?

Chapter 15

Movements of the Ankle and Foot

The relatively rigid structure comprising the human foot has evolved from the flexible grasping organ of the arboreal dwelling pre human The foot includes twenty six bones so grouped as to form a half dome The base of this half dome extends from the calcaneus along the lateral border of the foot to the distal ends of all five metatarsals The arch which occurs in the vertical plane

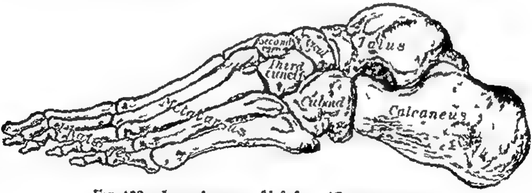

Fig 129 —Lateral aspect of left foot (*Gray's Anatomy*)

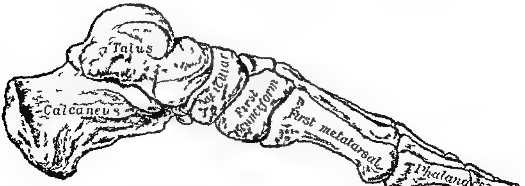

Fig 130 —Medial aspect of left foot (*Gray's Anatomy*)

4 Analyze the two styles of lifting shown in Figs 125, 126 and 127 From the kinesiological standpoint what are the advantages and disadvantages of each? Are there any structural factors involved in the selection of the style to be used by a given individual? Explain why Kono wears high heels but Schemansky does not

5 In a duel in 1547 Jarnac defeated Chastaigneraie by slicing through the muscle behind the left knee This is known in history as the *coup de Jarnac* What muscles would be affected by such a cut and what would be the results?

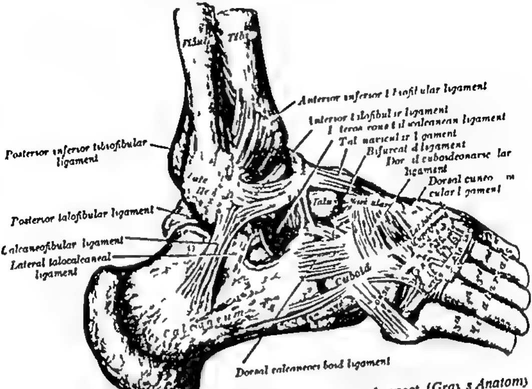

FIG 132 —Ligaments of the right ankle and tarsus Lateral aspect (Gray s Anatomy)

FIG 133 —Posterior aspect of left ankle joint (Gray s Anatomy)

running from the calcaneus to the distal end of the first metatarsal is commonly known as the longitudinal arch In walking weight is transmitted from the talus to all the peripheral weight bearing part of the foot The bones are held together by ligaments and the half domes are kept from flattening by ligaments, the plantar aponeurosis the tendons of the extrinsic muscles of the foot and the intrinsic muscles of the foot

The bones of the foot are as follows

Seven *tarsal* bones talus or astragalus, calcaneus navicular or scaphoid, cuboid, and three cuneiform bones numbered from within outward The movements of these bones have been carefully analyzed by Shephard[1]

FIG 131 —Coronal section through right talocrural and talocalcaneal joints (*Gray s Anatomy*)

Five *metatarsal* bones numbered from within outward

Fourteen *phalanges* three for each toe except the first which has two The actions of these bones and their interrelations are well described by Steindler[2]

The longitudinal arch is held in position primarily by the bow string ligaments—the long plantar ligament the plantar calcaneo cuboid ligament and the plantar calcaneo navicular (or spring) ligament (Fig 134) These are assisted by other ligaments and muscles of the foot Drew[3] has contrasted the great functional movement of the arches of uncivilized peoples with the rigidity of those of civilized peoples He attributes the latter to the splinting

body weight to the talus through an enlarged surface at the distal end known as the trochlea. A process of the tibia, the medial malleolus, continues on down the medial side of the talus articulating with its medial surface. The fibula bears little or no weight but passes down the lateral side of the talus forming the lateral malleolus which articulates with the lateral surface of the talus. In this way the talus fits up into a sort of flanged slot or mortise, which adds great stability to the joint. Medially the talus is bound to the tibia by the deltoid ligament which attaches to the malleolus (Fig. 134). This ligament also has bands which connect the malleolus with the calcaneus and navicular bone preventing either forward or backward displacement of the tibia. Laterally the joint is spanned by the anterior and posterior talofibular ligaments (Fig. 132) and the calcaneofibular ligament (Fig. 132). These ligaments are arranged not only to tie the joint together but also to prevent forward or backward displacement of the fibula.

The ankle permits about 60 degrees of voluntary movement. The amplitude can be increased by using the weight of the body. Starting from standing position the knees can be flexed until the tibia inclines forward 25 to 30 degrees with the foot flat on the floor, with further movement the heel is lifted by the posterior ligaments of the ankle joint. The front of the foot can be depressed through about 45 degrees. The axis of the ankle joint is parallel to that of the knee joint.

2. **Intertarsal Joints.** These are the articulations between the seven tarsal bones. Gliding movements are permitted by these arthrodial type joints.

3. **Tarso metatarsal Joints.** These are the articulations between the tarsal bones and the proximal ends of the five metatarsals. Gliding movements are permitted by these arthrodial type joints.

4. **Metatarso phalangeal Joints.** These are the articulations between the distal ends of the metatarsals and the proximal phalanges. The movements of these condyloid type joints are potentially the same as in the metacarpo phalangeal joints of the fingers. Flexion and extension, and slight abduction and adduction are permitted.

5. **Interphalangeal Joints.** These are hinge joints that permit flexion and extension of the toes.

The motions of the ankle and tarsal joints are conveniently named and simultaneously described, by considering them as foot motions. There are four foot motions.

1. Foot *dorsiflexion* (also called *foot flexion*) consists of raising the foot toward the anterior surface of the leg. Dorsiflexion takes place mostly in the ankle joint and slightly in the tarsal joints.

2. Foot *plantar flexion* (also called *foot extension*) consists of lowering the foot so as to bring its long axis in line with that of the leg. Plantar flexion takes place mostly in the ankle joint and slightly in the tarsal joints.

3. Foot *eversion* takes place when the sole is turned laterally or "outward". Eversion cannot be accomplished without simultaneously displacing the long axis of the foot into the "toe out" position. Eversion takes place only in the tarsal joints.

4. Foot *inversion* takes place when the sole is turned medially or "inward". Inversion cannot be accomplished without simultaneously displacing the

action of shoes, which effectively immobilize the joints of the foot of the wearer

The movements of the foot take place in several different joints

1 **Ankle joint** This is a hinge joint, formed by the articulation of the tibia and fibula with the talus The tibia and fibula are bound closely, chiefly by the interosseous membrane and ligaments but also by the anterior (Fig 132) and posterior inferior tibiofibular ligaments (Fig 133) and the inferior transverse ligament which also articulates with the talus The tibia transmits the

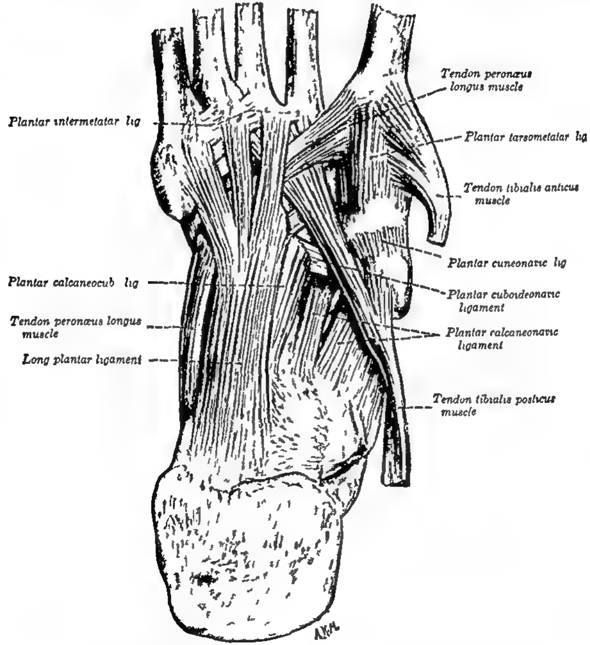

FIG 134 —Ligaments of the sole of the foot with the tendons of the peroneus longus tibialis posterior and tibialis anterior muscles (Quain)

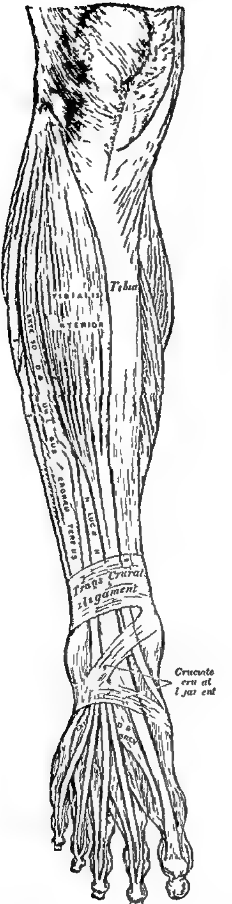

FIG 135 —Muscles on anterior aspect of right leg (*Gray's Anatomy*)

long axis of the foot into the "toe in or "pigeon toed position Inversion takes place only in the tarsal joints *

There are twelve muscles which are involved in producing the movements of the foot described above

Tibialis anterior	Soleus
Extensor digitorum longus	Peroneus longus
Peroneus tertius	Flexor digitorum longus
Extensor hallucis longus	Flexor hallucis longus
Gastrocnemius	Tibialis posterior
Plantaris	Peroneus brevis

In addition there are nineteen intrinsic muscles of the foot which aid in supporting the half domes and which produce the fine movements of the toes

EXTRINSIC MUSCLES OF THE ANKLE AND FOOT

TIBIALIS ANTERIOR

A slender muscle situated on the antero lateral aspect of the tibia (Figs 135 and 136)

Origin The upper two thirds of the lateral surface of the tibia and the corresponding portion of the interosseous membrane which joins the tibia and the fibula

Insertion The medial and under surface of the first cuneiform bone and the base of the first metatarsal

Innervation A branch of the deep peroneal nerve with fibers coming from the fourth and fifth lumbar and first sacral nerves

Structure The muscle fibers arise directly from the bone and are inserted obliquely into the tendon of insertion which is held down at the ankle by a ring ligament

Action Prime mover for dorsiflexion and inversion When this muscle is paralyzed the individual suffers from foot drop and may stub his toes on curbs or steps

EXTENSOR DIGITORUM LONGUS

Similar to the preceding and situated just laterally to it (Figs 135 and 136)

Origin Lateral condyle of the tibia, the upper three fourths of the anterior surface of the fibula and the adjacent interosseous membrane and covering deep fascia

Insertion Dorsal aspect of the four lesser toes and their extensor expansions

Innervation Branches of the deep peroneal nerve containing fibers from the fourth and fifth lumbar and first sacral nerves

Structure A penniform muscle with a long tendon beginning at the middle of the leg As it passes under the ring ligament of the ankle the tendon divides into four slips which pass to the toes

Action Prime mover for toe extension dorsiflexion and eversion

* Certain authors define *pronation* of the foot as a normal action composed of eversion in combination with abduction and *supination* as a normal action composed of adduction in combination with inversion In this text these terms have been reserved for use in consideration of foot defects such as talipes valgus and talipes varus

Origin Linea aspera and oblique popliteal ligament of the knee joint

Insertion Posterior part of the calcaneus

Innervation Branch of the tibial nerve, containing fibers from the fourth and fifth lumbar and first sacral nerves

Structure At the proximal end a fusiform belly 7 to 10 cm long is found between the heads of the gastrocnemius Its very long tendon lies between the gastrocnemius and soleus muscles

Action Very weak assistant for knee flexion and plantar flexion

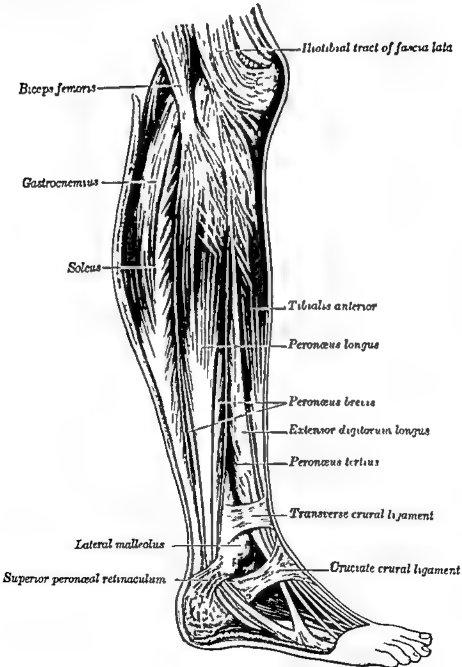

FIG 136 —The right lateral crural muscles (*Gray s Anatomy*)

PERONEUS TERTIUS

Often described as a portion of extensor digitorum longus (Fig 135) It has been found only in the feet of man and of the gorilla

Origin The lower third of the anterior surface of the fibula and the lower portion of the interosseous membrane

Insertion The dorsal surface of the base of the fifth metatarsal

Innervation A branch of the deep peroneal nerve with fibers from the fourth and fifth lumbar and first sacral nerves

Action Prime mover for dorsiflexion and eversion of the foot

EXTENSOR HALLUCIS LONGUS

A smaller muscle lying beneath the tibialis anterior and the peroneus tertius (Fig 135)

Origin The anterior surface of the fibula and of the interosseous membrane at the middle half of the leg

Insertion The base of the distal phalanx of the great toe

Innervation A branch of the deep peroneal nerve The fibers are from the fourth and fifth lumbar and first sacral nerves

Structure Like the preceding

Action Prime mover for extension of the great toe Assists with dorsiflexion and inversion

The four muscles just described, usually called the flexors of the foot are brought into action in walking running and all similar movements to raise the toes and front of the foot and prevent their striking or scraping on the ground The tibialis and the extensor digitorum longus are both needed to give even elevation of the foot the extensor of the great toe is included in the coordination People who have lost the use of this group of muscles scrape the foot on the ground at each step in walking

GASTROCNEMIUS

The large muscle that gives the rounded form to the calf of the leg (Fig 136)

Origin By two tendons from the posterior aspect of the condyles of the femur (Fig 137)

Insertion The posterior surface of the calcaneus (Fig 225)

Innervation Branches of the tibial nerve which contain fibers from the first and second sacral nerves

Structure The upper tendons are flattened the lower (tendon of Achilles) is very large and has a cross section like a letter T with the upright part between the right and left halves of the muscle and the crossbar on its posterior surface the fibers from the two upper tendons pass diagonally downward to join the sides of the tendon of Achilles at various levels

Action A prime mover for plantar flexion assists with knee flexion

PLANTARIS

Vestigial in man In most mammals it is larger than the gastrocnemius and flexes the toes [4]

Origin Linea aspera and oblique popliteal ligament of the knee joint

Insertion Posterior part of the calcaneus

Innervation Branch of the tibial nerve containing fibers from the fourth and fifth lumbar and first sacral nerves

Structure At the proximal end a fusiform belly 7 to 10 cm long is found between the heads of the gastrocnemius Its very long tendon lies between the gastrocnemius and soleus muscles

Action Very weak assistant for knee flexion and plantar flexion

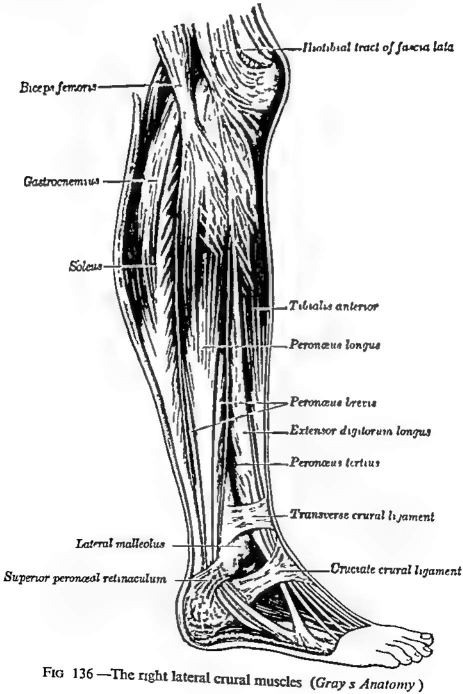

FIG 136 —The right lateral crural muscles (*Gray s Anatomy*)

SOLEUS

An associate of the gastrocnemius, lying immediately anterior to it (Fig 136)

Origin The upper part of the posterior surfaces of the tibia fibula, and interosseus membrane (Fig 223)

Insertion By the tendon of Achilles into the calcaneus

Innervation A branch of the tibial nerve which contains fibers from the first and second sacral nerves

Structure Penniform sheets

Action Prime mover for plantar flexion The soleus and gastrocnemius together form a functional unit sometimes termed the *triceps surae* Studies made by several investigators agree fairly well that the maximum force the gastrocnemius and soleus can exert in voluntary effort is about 450 kg , that is, the muscles of each calf can exert on the ball of the foot a force of about 225 kg They calculate the pull on the Achilles tendon is about three times as much [5] However, a recent investigation has obtained a maximum muscle force in the tendo calcaneus of about 438 kg or 3 9 kg per sq cm of cross section [6] When the knee is flexed to 90 degrees or more the gastrocnemius seems to be left out of the coordination leaving the work of extending the foot to the soleus In this position the heads of the gastrocnemius are so low that it cannot pull effectively

PERONEUS LONGUS

This muscle is remarkable for its great power in proportion to its size and for the long and tortuous course of its tendon of insertion It is situated along the fibula on the lateral side of the leg just beneath the skin (Fig 136)

Origin The lateral condyle of the tibia and the upper two thirds of the lateral aspect of the fibula (Fig 223)

Insertion The lateral side of the first cuneiform bone and the lateral side of the proximal end of the first metatarsal (Fig 226)

Innervation The superficial peroneal nerve with fibers from the fourth and fifth lumbar and first sacral nerves

Structure The fibers are short and arise directly from the fibula one of the best examples of simple penniform arrangement the tendon of insertion passes down behind the outer malleolus, turns forward around its lower end at an angle of about 60 degrees passes forward along the outer margin of the foot to the groove in the cuboid bone where it makes another turn of about 100 degrees then diagonally forward and across the sole of the foot to the place of insertion at the base of the great toe A sesamoid fibrocartilage (occasionally a bone) is usually developed where it changes direction at the cuboid bone

Action Prime mover for eversion assists with plantar flexion

FLEXOR DIGITORUM LONGUS

Situated on the medial aspect of the tibia

Origin The posterior surface of the body of the tibia from just below the popliteal line and from the fascia covering the tibialis posterior

Insertion The bases of the distal phalanges of the four small toes Each

tendon passes through an opening in the corresponding tendon of the flexor digitorum brevis (Fig 139)

Innervation Branch of the tibial nerve with fibers from the fifth lumbar and first sacral nerves

Action Prime mover for flexion of the second through fifth toes assists with plantar flexion and inversion

The importance of hypertrophying the toes flexors for drive in sports has been stressed by Loewendahl [7] Running in sand calls for powerful toe curling action and is an excellent conditioning exercise for these flexors but may result in soreness of these muscles if the individual is unaccustomed to it

FLEXOR HALLUCIS LONGUS

Situated on lateral aspect of fibula

Origin Inferior two thirds of the posterior surface of the fibula and from the lowest part of the interosseous membrane

Insertion Under surface of the base of the last phalanx of the great toe (Fig 139)

Innervation A branch of the tibial nerve with fibers from the first lumbar and first and second sacral nerves

Structure The tendon occupies nearly the whole length of muscle passes around the medial malleolus and runs forward along the medial side of the plantar aspect of the foot to its insertion

Action Prime mover for flexion of the great toe assists with plantar flexion and inversion If this muscle is injured it is difficult to maintain the equilibrium when standing on the toes

TIBIALIS POSTERIOR

Situated deep beneath the triceps surae on the posterior aspect of the tibia (Fig 137)

Origin The upper half of the posterior surface of the interosseous membrane and the adjacent parts of the tibia and fibula

Insertion The tuberosity on the inferior surface of the navicular, with offshoots to adjacent bones (Fig 226)

Innervation A branch of the tibial nerve with fibers from the fifth lumbar and first sacral nerves

Structure Simple penniform the tendon turns through 90 degrees around the medial malleolus

Action Prime mover for inversion, assists with plantar flexion Loewendahl[7] has emphasized the need for resistive exercise of this muscle in strengthening the ankle joints for sports, commenting that it is the anchor of the foot and ankle If it is weak the foot assumes a pronated position and the body is thrown out of alignment Knee and low back pains may result Resistive exercises for this muscle are essential for ice skating hockey skiing and other sports in which ankle control is of importance Such exercises should be performed in the standing position with the foot inverted

PERONEUS BREVIS

A small associate of the longus (Fig 137)

Origin The lower two thirds of the lateral surface of the fibula

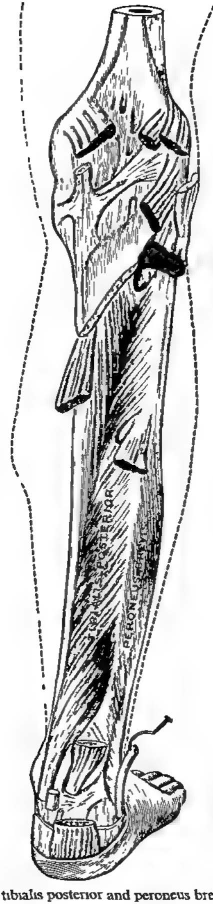

FIG 137 —The tibialis posterior and peroneus brevis of right foot

Insertion The tuberosity at the proximal end of the fifth metatarsal

Innervation A branch of the superficial peroneal nerve which contains fibers from the fourth and fifth lumbar and first sacral nerves

Structure Fibers arranged like the longus The muscle makes a similar turn around the outer malleolus forward and downward to the insertion

Action Prime mover for eversion, assists with plantar flexion

INTRINSIC MUSCLES OF THE FOOT

THE FIRST PLANTAR LAYER

ABDUCTOR HALLUCIS

Origin Primarily from the medial process of the tuberosity of the calcaneus (Fig 138)

FIG 138 —Muscles of the sole of the foot First layer (*Gray s Anatomy*)

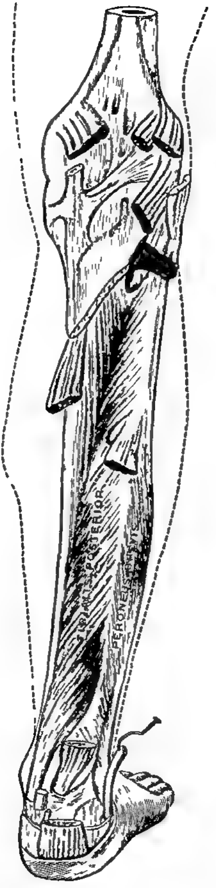

FIG 137 —The tibialis posterior and peroneus brevis of right foot

Innervation A branch of the medial plantar nerve with fibers from the fourth and fifth lumbar nerves

Action Flexes the second through fifth toes

ABDUCTOR DIGITI QUINTI

Origin Primarily from the lateral process of the tuberosity of the calcaneus (Fig 138)

Insertion Lateral side of the base of the first phalanx of the fifth toe

Innervation Lateral plantar nerve, containing fibers from the first and second sacral nerves

Action Spreads the fifth toe away from the fourth toe

THE SECOND LAYER

QUADRATUS PLANTAE

Origin Two heads, the medial surface and the lateral border of the inferior surface of the calcaneus (Fig 139)

Insertion Fuses with the tendon of the flexor digitorum longus

Innervation Lateral plantar nerve containing fibers from the first and second sacral nerves

Action Flexes the second through fifth toes

THE LUMBRICALES

Four small muscles numbered from the medial side (Fig 139)

Origin The tendons of the flexor digitorum longus excepting the first each springing from the two adjacent tendons

Insertion The tendons fuse with the tendons of the extensor digitorum longus on the dorsal surfaces of the first phalanges

Innervation The first by a branch of the medial plantar nerve containing fibers from the fourth and fifth lumbar nerves the remaining three by the lateral plantar nerve containing fibers from the first and second sacral nerves

Action Flex the proximal and extend the distal phalanges of the second through fifth toes

THE THIRD LAYER

FLEXOR HALLUCIS BREVIS

Origin Medial part of the inferior surface of the cuboid bone (Fig 140)

Insertion The tendon divides being inserted on each side of the base of the proximal phalanx of the big toe

Innervation Medial plantar nerve containing fibers from the fourth and fifth lumbar and first sacral nerves

Action Flexes the proximal phalanx of the big toe

ADDUCTOR HALLUCIS

Origin Two heads The oblique head arises from the proximal ends of the second third and fourth metatarsals The transverse head arises from the metatarso phalangeal ligaments of the third fourth and fifth toes (Fig 140)

Insertion Lateral side of proximal phalanx of the big toe

Insertion The medial side of the proximal end of the first phalanx of the great toe

Innervation Medial plantar nerve, with fibers from the fourth and fifth lumbar nerves

Action Spreads the great toe away from the second toe

FLEXOR DIGITORUM BREVIS

Occupies the central portion of the posterior surface of the foot (Fig 138)

Origin The medial process of the tuberosity of the calcaneus and the plantar aponeurosis

Insertion The tendons divide and are inserted into the sides of the second phalanges of the second through fifth toes

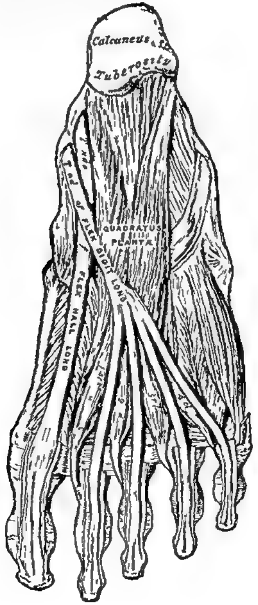

Fig 139 —Muscles of the sole of the foot Second layer (*Gray s Anatomy*)

THE FOURTH LAYER

DORSAL INTEROSSEI

Four of these bipenniform muscles between the metatarsal bones

Origin Each muscle arises by two heads from adjacent sides of the metatarsal bones which it lies between (Fig 141)

Insertion The proximal end of the first phalanges and the tendon of the extensor digitorum longus

Innervation Lateral plantar nerve containing fibers from the first and second sacral nerves

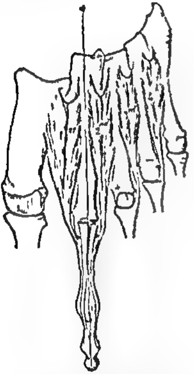

FIG 141 —Dorsal interossei of left foot (*Gray s Anatomy*)

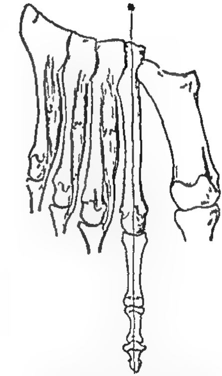

FIG 142 —Plantar interossei of left foot (*Gray s Anatomy*)

Action First interosseus draws the second toe toward the great toe The second third, and fourth draw the second third and fourth toes away from the great toe Flex the proximal and extend the distal phalanges of the second third and fourth toes

PLANTAR INTEROSSEI

Three muscles each of which lies under the metatarsal bones to which it is attached

Origin The medial sides of the bodies of the third fourth, and fifth metatarsal bones (Fig 142)

Insertion The medial sides of the proximal phalanges of the same toes and the tendons of the extensor digitorum longus

Innervation Lateral plantar nerve, containing fibers from the first and second sacral nerves

Action Draws the great toe toward the second toe

FLEXOR DIGITI QUINTI BREVIS

Origin Proximal end of the fifth metatarsal bone (Fig 140)

Fig 140 —Muscles of the sole of the foot Third layer (*Gray s Anatomy*)

Insertion Lateral side of the proximal end of the proximal phalanx of the little toe

Innervation Lateral plantar nerve containing fibers from the first and second sacral nerves

Action Flexes the proximal phalanx of the fifth toe

THE FOURTH LAYER

DORSAL INTEROSSEI

Four of these bipenniform muscles between the metatarsal bones

Origin Each muscle arises by two heads from adjacent sides of the metatarsal bones which it lies between (Fig 141)

Insertion The proximal end of the first phalanges and the tendon of the extensor digitorum longus

Innervation Lateral plantar nerve containing fibers from the first and second sacral nerves

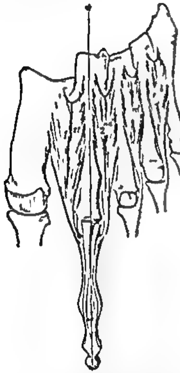

Fig 141 —Dorsal interossei of left foot (*Gray s Anatomy*)

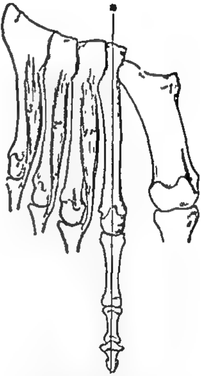

Fig 142 —Plantar interossei of left foot (*Gray s Anatomy*)

Action First interosseus draws the second toe toward the great toe The second third and fourth draw the second third and fourth toes away from the great toe Flex the proximal and extend the distal phalanges of the second third and fourth toes

PLANTAR INTEROSSEI

Three muscles each of which lies under the metatarsal bones to which it is attached

Origin The medial sides of the bodies of the third fourth and fifth metatarsal bones (Fig 142)

Insertion The medial sides of the proximal phalanges of the same toes and the tendons of the extensor digitorum longus

Innervation Lateral plantar nerve containing fibers from the first and second sacral nerves

Action Draw the third fourth, and fifth toes toward the second toe Flex the proximal and extend the distal phalanges of the third, fourth and fifth toes

THE DORSAL ASPECT

EXTENSOR DIGITORUM BREVIS

A broad, thin muscle

Origin Upper and lateral surface of the calcaneus (Fig 143)

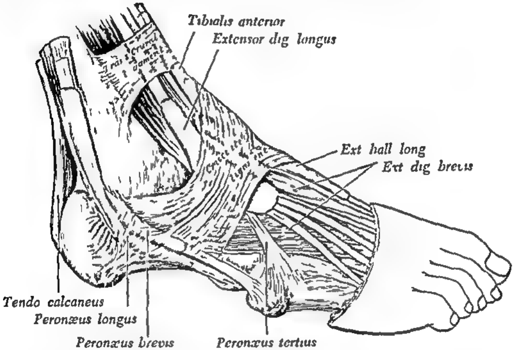

Fig 143 —Lateral aspect of right foot (*Gray s Anatomy*)

Insertion Ends in four tendons The most medial inserts into the dorsal surface of the proximal end of the first phalanx of the great toe the other three insert into the tendons of the extensor digitorum longus of the second third and fourth toes

Innervation Deep peroneal nerve containing fibers from the fifth lumbar and first sacral nerve

Action Extends the proximal phalanges of the first through fourth toes

KINESIOLOGY OF FOOT DEFECTS

The evolution of the foot from a grasping organ characterized by powerful intrinsic muscles into a comparatively rigid mechanism designed for locomotion has been only partially successful Most babies are flat footed when they begin to walk The short plantar muscles gradually tighten up the anterior and posterior tibials lift the inner border and the longitudinal arch forms [8] No one type of arch can be considered normal and its height and shape are of no value in estimating the strength or usefulness of the foot [9]

There is, however, a lack of general agreement in regard to when a foot is normal either in its morphology or its function It has been reported[3,10] that the feet of primitive peoples who do not wear shoes are extremely mobile They appear almost flat when weight bearing in the relaxed state, but become highly arched in action Such feet may tire easily under prolonged standing but their functional capabilities are indicated by the fact that they are said to be frequently seen in runners and ballet dancers The feet of most civilized men, however, are characterized by a pronounced longitudinal arch which is not depressed during weight bearing nor raised during action The static condition is attributed to the fact that modern shoes in effect place the foot in a splint The ligaments shorten the joint capsules contract adhesions form, and the arch becomes relatively rigid

The earlier idea that failure in the strength of the muscles of the longitudinal arch was the cause of most foot defects has been ridiculed by Morton,[11] who contends that the effect of gravity, acting through the body weight, is the direct cause of most ills to which the foot is subject In either event there has been a long standing controversy between kinesiologists concerning the relative importance of the ligaments and the muscles in supporting the arch Work by Morton[12] and Steindler[2] has lent powerful support to the concepts that the ligaments are of primary importance and the muscular apparatus of only secondary importance Summarizing various electromyographic studies, Basmajian declared It now seems to be beyond controversy that tibialis anterior peroneus longus and the intrinsic muscles of the foot play no important active role in normal static support of the long arches of the foot [13]

The most common deformities of the foot are the following

1 Talipes calcaneus Paralysis of the triceps surae, or of the peroneus longus or of both permits the anterior muscles to elevate the forefoot so that the weight is carried on the heel

2 Talipes equinus Paralysis of the tibialis anterior, the extensor digitorum longus or of other dorsiflexors permits the triceps surae to go into contracture so that the heel is raised and the weight is carried on the toes Mild grades of talipes equinus are common in women who commonly wear high heeled shoes In such cases there is an overstretching of the tibialis anterior and the dorsal flexors with an adaptive shortening of the tendo Achillis Callosities and hammer toes are a common after effect

3 Talipes varus Paralysis of the peroneus longus and/or peroneus brevis may allow the anterior and posterior tibials to pull the foot into a position in which the sole is turned inward

4 Talipes valgus Loss of the posterior tibials and/or the intrinsic plantar muscles or contracture of the peroneus longus may cause the sole of the foot to turn outward

5 Pes cavus occurs when loss of the triceps surae permits the flexors to draw the calcaneus forward the talus dorsiflexes and the plantar fascia contracts A very high arch is formed tightening the long extensors of the toes The toes are cocked up and the condition known as clubfoot occurs

6 Pes planus The ankles deviate inward, throwing an abnormally high percentage of the body weight on the plantar ligaments The anterior and posterior tibials and the intrinsic plantar muscles are stretched allowing the foot to sag an action which may continue until its medial portion contacts

the ground Pes planus may be recorded as 1st, 2nd, or 3rd degree depending upon the extent of the sagging Weak foot, pronated foot and flat foot may be successive stages of the same defect

The propelling force of locomotion is provided chiefly by the gastrocnemius and the soleus It was perhaps Gottlieb[14] who first called attention to the antagonism in relation and function existing between the triceps surae, whose action tends to flatten the longitudinal arch, and the short plantar muscles, whose actions contribute to its retention, but his theories have been considerably elaborated by Jones [15] Briefly, it is their contention that stress on the longitudinal arch is directly proportional to the pressure borne by the ball of the foot For a person to raise himself on the ball of one foot, as in walking requires a pull on the Achilles tendon equal to twice the body weight By far the greater portion of this force is exerted by the triceps surae The posterior tibials flexor hallucis longus flexor digitorum longus and peroneus longus are considered relatively insignificant as plantar flexors, their mechanical advantage and absolute strength are such that they account for not over 5 per cent of the pressure in the ball of the foot in plantar flexion

Not more than 15 to 20 per cent of the tension stresses in the arch is borne by the long leg muscles the major support for the arch is furnished by the plantar ligaments the plantar aponeurosis and the short plantar muscles If the powerful triceps surae shorten, they tend to displace the front part of the calcaneus downward The superimposed weight of the body causes the adjoining scaphoid and astragalus to sink the plantar muscles and ligaments are overstretched and the foot is flattened

Pressure of arch supports between the ball of the foot and the heel cannot reduce the stress on the arch incident to the pull of the triceps surae

Certain physical conditions may predispose a weak foot to develop pes planus Among them are

1 An inactive life in childhood and adolescence may fail to develop the strength of muscles and ligaments needed to support the body weight

2 A laying on of adipose tissue in later life may increase the load on the arches beyond the point which the muscles and ligaments can tolerate

3 Constant walking on hard even surfaces such as cement sidewalks gives too hard an impact with each step and fails to provide the muscular development resulting from walking in open fields where the uneven but softer surface causes the foot to take different positions and thus distribute the work load among the various muscles

4 Structural defects may predispose to clinical disorders Morton has stressed the role of a short first metatarsal as a definite morphological feature inducing a major disturbance in the function of the entire foot [16]

5 Pes planus can sometimes be traced to a toxic condition brought about by infection with a resulting weakening of the supporting tissues [17]

6 Badly fitting shoes have a large place in the cause of foot ills Ober[18] has given the following as the requirements for a satisfactory shoe for the *normal foot*

a Sufficient length so that the end of the great toe is not against the end of the shoe, but not so long that the foot slides forward from the heel upper

b The front must be wide enough not to cramp the toes but snug enough

so that the forefoot will not slide about The heel must be held snugly both at the sides and behind

c Sufficient height over the instep so that the instep is not pushed downward

d The lines of the shoe must correspond to the lines of the sole of the foot

e The shank fit is most important If the whole sole of the foot is utilized as the weight bearing surface, it will be mechanically easier to carry the distributed load This requires selection of a shoe whose shank fits the individual arch

High heels are almost unanimously condemned by the medical profession They have been termed essentially a prosthesis for a deformity," and from the physiological standpoint are the most destructive factor in foot physiology [19] It is contended that they

1 Cause a decrease in the tone of the postural muscles and an increase in tension on the plantar fascia

2 Shorten the leverage of the foot for propulsion and increase the muscular effort required in the pushoff

3 Decrease the postural power of the erectors of the tibia A structural shortening of the tendo Achillis results and the relaxation of the hamstrings upsets the whole postural mechanism

4 Keep the toes in more or less complete dorsiflexion

5 Increase the weight thrown on the articular surface of the metatarsal heads especially of the slender middle metatarsals which are essentially non weight bearing structures

From all of this it follows that once a longitudinal arch has flattened it cannot be elevated by exercise of the muscles of the foot, as it is impossible for them to exert a tension great enough to raise a fallen arch The most important role of corrective exercises would seem to lie in strengthening a weak foot before it collapses Foot exercises have three main objectives

1 To improve the local circulation

2 To stabilize the foot in the correct position in relation to the leg

3 To act as self manipulative forces which will improve the range of movement of the individual joints [12]

If it is decided to utilize corrective exercises it is usually considered good policy to employ non weight bearing movements in the early states of treatment Suitable movements are described in texts on corrective exercise[20] and need not be elaborated upon here After some progress has been made and the strength of the muscles restored to some extent weight bearing exercises in the standing position are ordinarily prescribed In general these exercises are designed to strengthen the tibials and throw the body weight on the lateral borders of the feet

Foot disabilities of a different type may result from long continued crossing of the legs crouching squatting or kneeling In some instances this may result in the compression of the peroneal nerve against the femur or fibula or in a stretching of the nerve especially in the case of tall slender long legged persons The superficial peroneal nerve innervates the peroneus longus and brevis which evert the foot the deep peroneal nerve innervates the dorsi flexors of the foot and the extensors of the toes If its function is interrupted

foot drop results When the common peroneal nerve is injured the affected foot cannot be dorsiflexed at the ankle, the toes cannot be extended and inversion of the foot occurs A hazard of weight reduction is that the disappearance of the fat may deprive the peroneal nerve of a certain amount of protection against the occurrence of injuries resulting from pressure [21]

Implications for Athletic Training The ankle joint is poorly supported by muscles and ligaments but in the erect position must support the entire weight of the body As a result it is frequently injured in such sports as foot ball basketball baseball, judo and skiing Some trainers believe that shin splints and certain knee troubles result from the dropping of the longitudinal arch of the foot Preseason exercises designed to strengthen the musculature surrounding the joints and the use of protective wrappings during practice and competition may aid in the prevention of such disabilities but cannot be expected to eliminate them entirely Claims have been made that reinforcing the ankle results in an increased number of knee injuries

Eighty five per cent of all injuries to the ankle are *inversion injuries*, in which the foot is forced inward in relation to the leg Since the medial malleolus is short, the talus may rotate over it when suffering an inversion injury The result is that such injuries tend to be primarily a tearing of the lateral ligament In *eversion injuries* the foot is forced outward in relation to the leg Since the talus cannot rotate over the longer lateral malleolus it may break it off or even more severe damage to the bones and ligaments of the ankle and leg may result

Such considerations make it important to analyze the forces applied to an injured ankle in order to determine the mechanics of the injury and thus obtain a better diagnosis [22]

If a severe injury of this type does occur and the patient is in bed for some time the pull of the calf muscles will almost certainly result in plantar flexion (foot drop) Tight bed covers will accentuate this tendency A footboard is a useful aid in preventing this deformity and the patient should be taught a few simple exercises such as those with a towel designed to stretch the tendo Achillis

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TABLE 13 —Ankle and Foot Muscles and Their Actions

EXTRINSIC MUSCLES	*ANKLE AND FOOT*				*TOES*	
	Dorsiflexion	*Plantar flexion*	*Inversion*	*Eversion*	*Flexion*	*Extension*
Tibialis anterior	P M		P M			
Extensor hallucis longus	P M			P M		P M *
Peroneus tertius	P M			P M		
Extensor hallucis longus	Asst		Asst			P M **
Gastrocnemius		P M				
Plantaris		Asst				
Soleus		P M				
Peroneus longus		Asst		P M		
Flexor digitorum longus		Asst	Asst		P M *	
Flexor hallucis longus		Asst	Asst		P M **	
Tibialis posterior		Asst	P M			
Peroneus brevis		Asst		P M		

INTRINSIC MUSCLES

<table>
<tr><td>Abductor hallucis</td><td colspan="2">Spreads great toe away from 2nd toe</td></tr>
<tr><td>Flexor digitorum brevis</td><td colspan="2">Flexes the 2nd through 5th toes</td></tr>
<tr><td>Abductor digiti quinti</td><td colspan="2">Spreads 5th toe away from 4th toe</td></tr>
<tr><td>Quadratus plantae</td><td colspan="2">Flexes the 2nd through 5th toes</td></tr>
<tr><td>Lumbricales</td><td colspan="2">Flex proximal phalanx and extend distal phalanx of 2nd through 5th toes</td></tr>
<tr><td>Flexor hallucis brevis</td><td colspan="2">Flexes proximal phalanx of the great toe</td></tr>
<tr><td>Adductor hallucis</td><td colspan="2">Draws the great toe toward 2nd toe</td></tr>
<tr><td>Flexor digiti quinti brevis</td><td colspan="2">Flexes proximal phalanx of 5th toe</td></tr>
<tr><td>1st dorsal interosseous</td><td>Draws 2nd toe toward the great toe</td><td rowspan="3">Also flex proximal phalanx and extend distal phalanx of 2nd through 4th toes</td></tr>
<tr><td>2nd 3rd & 4th dorsal interosseous</td><td>Draw 2nd 3rd & 4th toes away from the great toe</td></tr>
<tr><td>Plantar interossei</td><td>Draw 3rd 4th & 5th toes away from 2nd toe</td></tr>
<tr><td>Extensor digitorum brevis</td><td colspan="2">Extends proximal phalanx of 1st through 4th toes</td></tr>
</table>

* 2nd through 5th toes only
** Great toe only

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LABORATORY EXERCISES

1 What relationship might be found between success in swimming and the size of the feet?

2 What relationship might be found between the length of the foot and success in jumping or running?

3 What relationship might be found between the length of the calcaneus and the girth of the gastrocnemius?

4 Why do girls accustomed to the use of high heeled shoes experience discomfort in the calves when wearing low heeled shoes?

5 An old parlor trick consists of having a person stand with his nose and abdomen touching the edge of an open door He is then challenged to rise on tip toe Why does he find this impossible?

6 With the toes held upward try to raise the heels off the floor Why is this difficult?

7 What position should the foot be in when it is taped to reinforce an injured ankle?

8 What are the best progressive resistance exercises to develop the tibialis posterior?

9 Discuss the common practice of having individuals with flat feet exercise by rising on the toes in the light of the Gottlieb Jones theories What type of exercise might they recommend for the triceps surae of those exhibiting this condition?

10 It is said that the most common type of fall in skiing is with the knee and ankle abducted and externally rotated Analyze the kinesiology involved in injuries of this type

Chapter 16

Movements of the Spinal Column

THE bony axis of the trunk, called the spinal column, consists of 33 vertebrae, 24 of these are joined to form a flexible column Seven vertebrae are in the neck and are called cervical vertebrae 12 are in the region of the chest and are called thoracic or dorsal vertebrae 5 are in the lumbar region 5 are fused together to form the sacrum, the rear portion of the pelvis, the lower 4 are only partially developed and form the coccyx The spinal column is flexible above the sacrum upon which the flexible portion rests Each vertebra bears the

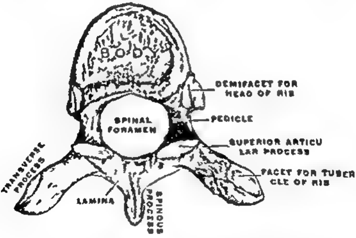

FIG 144 —A thoracic vertebra seen from above

weight of all parts of the body above it and since the lower ones have to bear much more weight than the upper ones the former are much the larger The flexibility of the column makes it possible to balance the weight upon the vertebrae in sitting and standing

Each vertebra has several points of interest The body or centrum is the largest portion and the most important since the weight is transmitted through it passing to the rear are the two pedicles then the two laminae the five

enclosing the spinal foramen A spinous process extends to the rear, and a transverse process from each side Four articular processes two above and two below, have articulations with the next vertebrae Beneath each pedicle is an intervertebral notch leaving a place for nerves to leave the spinal cord Besides these points to be found on all vertebrae, the thoracic vertebrae also have four articular processes or facets for the attachment of the ribs (Fig 144)

The skeleton of the chest or thorax includes the sternum and twelve pairs of ribs, a pair for each thoracic vertebra The ten upper ribs are attached to the sternum by the costal cartilages the lower two being attached only to the vertebrae

The vertebrae are separated by elastic disks of cartilage called the inter vertebral disks which are firmly joined to the bodies of the vertebrae and which permit movement of the column because of their elasticity These disks are composed of a centrally located deformable mass, the nucleus pulposus, which is surrounded by a heavy and strong layer of fibrocartilage the annulus fibrosus The deformable disk permits motion between the verte brae while providing a cushion for them The ends of each disk are closed by thin cartilaginous plates which adhere tightly to the bony surfaces of the verte brae Besides the union through the disks the vertebrae are joined by liga ments the bodies by an anterior and a posterior common ligament extending from the skull to the sacrum along their front and rear surfaces and by short lateral ligaments joining the bodies of adjacent vertebrae, the laminae are joined by the subflava ligaments which enclose the spinal canal and the spinous processes by the interspinous ligaments In the cervical region these processes are short and the interspinous ligaments are replaced by a single strong elastic ligament, the ligamentum nuchae or ligament of the neck In quadrupeds this ligament has to support the weight of the head and is much larger than in man (Fig 145)

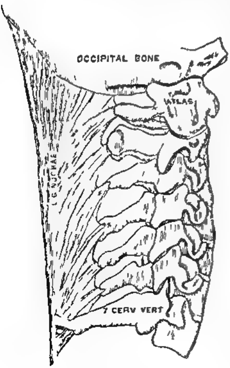

Fig 145 —The ligament of the neck

The normal spinal column is approx imately straight when viewed from the front or rear, it has a slight curve to right in the thoracic region supposed by some to be due to the pressure of the aorta and by others to the pull of the right trapezius and rhomboid which are used more than the muscles of the left side by right handed individuals This deviation from a straight line is too slight to be observed in the normal liv ing subject

When the spinal column is viewed from the side it presents four so called normal curves cervical and lumbar curves concave to the rear and thoracic and sacral curves convex to the rear These curves merge gradually into one

another the only approach to an angle being where the last lumbar vertebra joins the sacrum, the sharp bend here is due to the fact that the top of the sacrum slants forward about 45 degrees with the horizontal, giving the sacral angle (Fig 146)

The thoracic curve exists before birth and is chiefly due to the shape of the bodies of the vertebrae which in this region are slightly thinner at their

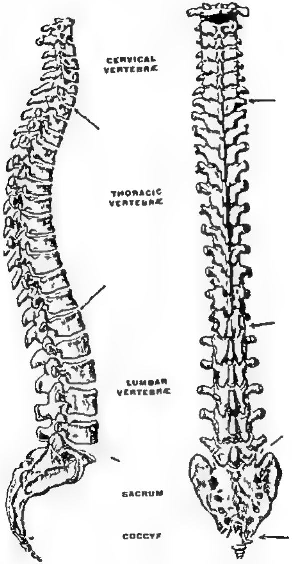

FIG 146—The spinal column

front edges (see Fig 146) The cervical and lumbar curves are not present in the infant which has a single curve convex to rear through the entire extent of the spine The cervical curve is formed by the action of the infant's muscles when he begins to sit up and hold his head erect and later to a more marked extent when he raises his head to look forward while creeping The lumbar curve is formed in a similar way when he first stands on his feet Up to this time the child's hip joints are kept flexed to a considerable extent

even when he lies on his back he seldom extends the hips fully When he begins to stand on his feet the iliofemoral band is put on a stretch for the first time, holding the pelvis tilted forward, to rise to erect position he has to fully extend the spine in the lumbar region which gives the normal curve Until he develops more strength in his legs and in the lumbar region and perfects the coordination his position is somewhat stooped

Movements of the spinal column take place by compression and traction of the elastic disks and by gliding of the articular surfaces upon each other Bending the trunk forward bringing the face toward the pubes is called flexion, the opposite movement as far as the normal position is called extension, backward movement beyond a normal posture is hyperextension bending sidewise is called lateral flexion and rotation on a vertical axis is called rotation or torsion

Except for the first two cervical vertebrae there is relatively little movement in each individual joint although the total movement of all the joints may appear to be large The ligaments joining the individual vertebrae are strong thick and taut and permit little movement Some regions are more mobile than others partly because the ligaments are less taut If the intervertebral disks are thick more compression is possible, yielding a greater range of motion In the thoracic region the overlapping and close proximity of the downward deflected spinous processes limit hyperextension and the ribs, which make the spine a part of a semi rigid cage, limit anterior and lateral movement The position of the articular facets govern the direction and to some extent the amount of motion

Flexion takes place in all regions of the spine but is most free in the lumbar region By voluntary flexion young subjects can usually obliterate the lumbar and cervical curves and increase the thoracic curve The shape of the articular processes in the lumbar region permits flexion and extension while limiting other movements The total amount of flexion possible in the spine is apt to be overestimated because the movements in the hip and in the joint between the head and the spine are easily mistaken for actual flexion of the trunk

Extension is free in normal subjects hyperextension is possible to a slight extent in the cervical and thoracic regions and to a much greater extent in the lumbar region and in the lower two thoracic segments

Lateral flexion is possible to a slight degree at all levels, but is most free at the junction of the thoracic and lumbar regions The ribs prevent much lateral movement in the region of the chest and the interlocking processes prevent it in the lumbar region Considerable lateral movement is possible in the neck

Rotation is most free in the upper parts of the spine and less free as we pass downward being prevented in the lumbar region by the processes The shape of the articular processes permits rotation above the limitation in the chest region being due to the ribs Rotation is said to be to right or left according to the way it would turn the face

Lateral flexion and rotation of the spine are usually described separately by authors on anatomy although the two movements never occur separately lateral flexion of the trunk always involves rotation and rotation of the trunk always involves lateral flexion

The presence of rotation accompanying all lateral flexion of the trunk

explained by a law of mechanics stating that if a flexible rod is bent first in one plane and then, while it is in this bent position it is bent again in a plane at right angles to the first it always rotates on its longitudinal axis at the same time When the subject bends forward giving a condition always present in the thoracic region it puts a tension on the ligaments at the rear (subflava and interspinous) that makes them resist lateral flexion more than usual, while the weight bearing down on the front edges of the bodies, aids in the lateral bending The result is that the bodies of the vertebrae go farther away from the vertical than do the spinous processes during lateral flexion The general principle which is self evident and which helps one to remember in which direction the rotation will be is that the concave side of the normal curve being under pressure, turns to a convex side of the lateral curve It follows that in the thoracic region a lateral bend rotates the spinous processes to the concave side and in the lumbar region to the convex side

The first and second cervical vertebrae deserve special attention because of their unique structure and function The first called the *atlas* has no centrum but is a bony ring surrounding the spinal foramen The spinous process is flattened but the two transverse processes are long On its upper surface it has two large concave articular surfaces which accommodate the occipital condyles of the skull These atlanto occipital joints allow considerable flexion and extension of the head The joint has a loose capsule but is spanned by two strong ligaments the anterior and posterior atlanto occipital ligaments

The second vertebra called the *axis* has a short peg called the *odontoid process* which extends vertically from its centrum into the spinal foramen of the atlas where a very large ligament separates it from the spinal cord This process serves as a pivot around which the atlas rotates rather freely making it possible to rotate or shape the head from side to side Movement in these two joints is relatively free compared to the other intervertebral articulations

The muscles which produce spinal movements exist in bilateral pairs Except for the quadratus lumborum all spinal muscles are movers for either flexion or extension in accordance with the following classification

Pure Lateral Flexor—Quadratus lumborum

Flexors—	Rectus abdominis External oblique Internal oblique Sterno cleido mastoideus 3 Scaleni Longus colli Longus capitus Rectus capitus anterior Rectus capitus lateralis Psoas
Extensors—	Intertransversarii Interspinales Rotatores Multifidus Semispinalis dorsi Semispinalis cervicis

Semispinalis capitis
Iliocostalis lumborum
Iliocostalis dorsi
Iliocostalis cervicis
Longissimus dorsi
Longissimus cervicis
Longissimus capitis
Spinalis dorsi
Spinalis cervicis
Splenius cervicis
Splenius capitis
4 Suboccipital muscles

PURE LATERAL FLEXOR

QUADRATUS LUMBORUM

The four sided muscle of the loins is a flat sheet of fibers on each side of the spinal column beneath the iliocostalis (Fig 151)

Origin The crest of the ilium the ligament, and the transverse processes of the lower four lumbar vertebrae

Insertion The transverse processes of the upper two lumbar vertebrae and the lower border of the last rib

Innervation Branches of the twelfth thoracic and first lumbar nerves

Structure A flat sheet of fibers directed mainly in a vertical direction

Action Prime mover for lateral flexion to the same side When both of these muscles act together, they depress the last ribs and assist in holding them down when the diaphram contracts Knapp[1] believes that its function is largely to stabilize the spine Paralysis of the oblique fibers on one side causes a drop pelvis on the opposite side and is one cause of scoliosis

THE FLEXORS OF THE SPINE

RECTUS ABDOMINIS

A rather slender muscle extending vertically across the front of the ab dominal wall The right and left recti are separated by a tendinous strip about an inch wide called the *linea alba* (white line) (Fig 147)

Origin The crest of the pubis

Insertion The cartilages of the fifth sixth and seventh ribs

Innervation Branches of the seventh to the twelfth intercostal nerves

Structure Parallel fibers crossed by three tendinous bands The lower end of the rectus passes through a slit in the transversalis and lies beneath it

Action Prime mover for spinal flexion contraction of one rectus abdominis alone assists with lateral flexion to the same side In standing position with the pelvis as the fixed point the rectus will pull downward on the front of the chest exerting its force on two sets of joints those of the ribs and those of the spinal column If the ribs are free to move they will be depressed if they do not move or after they have moved as far as they can move it will flex the trunk Unlike most muscles previously studied the rectus abdominis usually follows a curved line when at rest and the first effect of its action will be to flatten the abdominal wall so as to bring it into a straight line

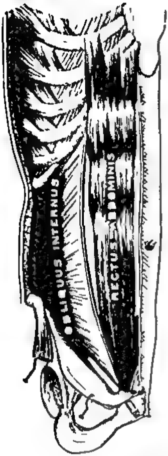

FIG 147 —Rectus abdominis and internal oblique

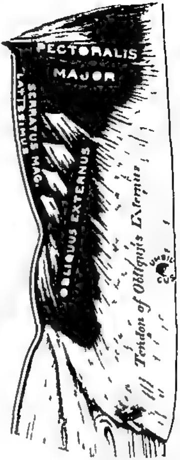

FIG 148 —External oblique

Electromyographic studies[2] indicate that the contraction of the rectus abdominis and external oblique muscles is an important factor limiting the depth of voluntary maximal inspiration It is believed that these muscles complete expiration rather than initiate it

EXTERNAL OBLIQUE

This muscle covers the front and side of the abdomen from the rectus abdominis to the latissimus (Fig 148)

Origin By saw tooth attachments to the lower eight ribs in alternation with those of the serratus anterior and latissimus

Insertion The front half of the crest of the ilium, the upper edge of the fascia of the thigh the crest of the pubis and the linea alba

Innervation Branches of the eighth to twelfth intercostal nerves and iliohypogastric and ilioinguinal nerves

Structure A sheet of parallel fibers extending diagonally sideward and upward from the origin the fibers of the pair forming a letter V on the front of the abdomen

Action Prime mover for flexion lateral flexion to the same side and rotation to the opposite side The line of pull is too nearly coincident with the

line of the rib it joins to give it much power to depress the chest If the muscle of one side acts alone it will pull the insertion forward and downward causing a combination of flexion lateral flexion and rotation to the opposite side if both muscles of the pair act at once the lateral pulls and the rotational tendencies are neutralized giving pure flexion of the spinal column The external oblique will tend to flatten the abdomen even more than the rectus because of its curved position around the side and front of it

INTERNAL OBLIQUE

Situated beneath the externus, with fibers running at nearly right angles to those of the outer muscle (Fig 147)

Origin The lumbar fascia the anterior two thirds of the crest of the ilium and the lateral half of the inguinal ligament

Insertion The cartilages of the eighth ninth and tenth ribs and the linea alba

Innervation Branches of the eighth to twelfth intercostal nerves and the iliohypogastric and ilioinguinal nerves

Structure A sheet of slightly radiating fibers forming with the opposite muscle an inverted V on the front of the abdomen

Action Prime mover for flexion, lateral flexion to the same side, and rotation to the same side Pulling downward and sideward on the front of the chest and abdomen, the internal oblique of one side will flatten the abdomen rotate to the same side, and flex the trunk working with its fellow it will cause pure flexion

The rectus and the two oblique muscles of the abdomen act together in all movements of vigorous flexion of the trunk, as in rising to erect sitting position when lying on the back When the movement begins slowly, the head being lifted first, the rectus acts alone the obliques joining in when the shoulders begin to rise In lateral flexion the abdominal muscles of one side act in rotation the external of the opposite side acts with the internal oblique of the same side

Paralysis of the abdominal muscles gives rise to an excessive lumbar curve, produced by the unopposed action of the extensors In the erect position these muscles are in continual contraction possibly to protect the inguinal region from rupture [3] in addition to assisting in the maintenance of the posture

STERNO CLEIDO-MASTOIDEUS

A pair of prominent muscles forming a letter V down the front and sides of the neck

Origin The anterior aspect of the sternum and medial (inner) third of the superior and anterior surfaces of the clavicle (Cleido is the Latin root referring to the clavicle) (Fig 149)

Insertion The mastoid process of the skull

Innervation The spinal portion of the accessory nerve and branches from the anterior rami of the second and third cervical nerves

Structure Two bundles of parallel fibers uniting into a single bundle above the center

Action Acting on the head and cervical spine it is a prime mover for flexion lateral flexion and rotation to the opposite side If the head is stabilized it

may act as a muscle of respiration This will be discussed further in the following chapter

SCALENI

Three muscles, the scalenus anterior scalenus medius and scalenus posterior, named from their relative positions and their triangular form as a group (Fig 150)

Origin The transverse processes of the cervical vertebrae

Insertion The scalenus anterior and scalenus medius insert on the superior surface of the first rib the scalenus posterior on the second rib

Innervation The scalenus anterior and scalenus medius receive branches from the lower cervical nerves The posterior scalenus receives fibers from the anterior rami of the last three cervical nerves

Structure Longitudinal fibers tendinous at each end

Action Prime mover for lateral flexion and assistant mover for flexion of the cervical spine If the head is stabilized it may act as a muscle of respiration This will be discussed further in the following chapter

LONGUS COLLI

Origin Anterior tubercles of the transverse processes of the third to fifth cervical vertebrae and the anterior surface of the bodies of the last three

Fig 149 —Muscles of the neck Lateral view (*Gray s Anatomy*)

line of the rib it joins to give it much power to depress the chest If the muscle of one side acts alone it will pull the insertion forward and downward, causing a combination of flexion lateral flexion and rotation to the opposite side, if both muscles of the pair act at once the lateral pulls and the rotational tendencies are neutralized giving pure flexion of the spinal column The external oblique will tend to flatten the abdomen even more than the rectus because of its curved position around the side and front of it

INTERNAL OBLIQUE

Situated beneath the externus, with fibers running at nearly right angles to those of the outer muscle (Fig 147)

Origin The lumbar fascia the anterior two thirds of the crest of the ilium and the lateral half of the inguinal ligament

Insertion The cartilages of the eighth ninth and tenth ribs and the linea alba

Innervation Branches of the eighth to twelfth intercostal nerves and the iliohypogastric and ilioinguinal nerves

Structure A sheet of slightly radiating fibers forming with the opposite muscle an inverted V on the front of the abdomen

Action Prime mover for flexion, lateral flexion to the same side and rotation to the same side Pulling downward and sideward on the front of the chest and abdomen the internal oblique of one side will flatten the abdomen rotate to the same side, and flex the trunk working with its fellow it will cause pure flexion

The rectus and the two oblique muscles of the abdomen act together in all movements of vigorous flexion of the trunk as in rising to erect sitting position when lying on the back When the movement begins slowly, the head being lifted first, the rectus acts alone the obliques joining in when the shoulders begin to rise In lateral flexion the abdominal muscles of one side act in rotation, the external of the opposite side acts with the internal oblique of the same side

Paralysis of the abdominal muscles gives rise to an excessive lumbar curve, produced by the unopposed action of the extensors In the erect position these muscles are in continual contraction possibly to protect the inguinal region from rupture [3] in addition to assisting in the maintenance of the posture

STERNO CLEIDO MASTOIDEUS

A pair of prominent muscles forming a letter V down the front and sides of the neck

Origin The anterior aspect of the sternum and medial (inner) third of the superior and anterior surfaces of the clavicle (Cleido is the Latin root referring to the clavicle) (Fig 149)

Insertion The mastoid process of the skull

Innervation The spinal portion of the accessory nerve and branches from the anterior rami of the second and third cervical nerves

Structure Two bundles of parallel fibers uniting into a single bundle above the center

Action Acting on the head and cervical spine it is a prime mover for flexion lateral flexion and rotation to the opposite side If the head is stabilized it

RECTUS CAPITIS LATERALIS

Origin Superior surfaces of the transverse processes of the atlas
Insertion Inferior surfaces of the jugular process of the occipital bone
Innervation Branches of the first and second cervical nerves
Action Assistant movement for lateral flexion of the head

THE EXTENSORS OF THE SPINE

INTERTRANSVERSARII

Pairs of small muscles anterior and posterior, on each side of the spine, joining the transverse processes of adjacent vertebrae They extend from the atlas to the first thoracic vertebra and from the tenth thoracic vertebra to the last lumbar vertebra The nerve supply is from both the anterior and posterior rami of the spinal nerves

Action Prime mover for lateral flexion of the spine If both sides act together they are prime movers for extension and hyperextension of the spine

INTERSPINALES

Pairs of small muscles joining the spinous processes of adjacent vertebrae one on each side of the interspinal ligament Continuous in the cervical region extending from the axis to the second thoracic vertebra and in the lumbar region from the first lumbar vertebra to the sacrum They are innervated by the posterior rami of the spinal nerves

Action Prime movers for extension and hyperextension of the spine

ROTATORES

A series of pairs of small muscles extending from the sacrum to the axis Their fibers run upward and medially

Origin The transverse processes of the vertebrae

Insertion The bases of the spinous processes of the first and second vertebrae above

Innervation Posterior rami of the spinal nerves

Action Prime movers for rotation of the spine to the opposite side If both sides act together they are prime movers for extension and hyperextension of the spine

MULTIFIDUS

A series of pairs of small muscles found the full length of the spine just superficial to the rotatores The fibers run upward and medially spanning two or three intervetebral spaces before inserting (*Fig* 151)

Origin The back of the sacrum the dorsal end of the iliac crest the transverse processes of the lumbar and the thoracic vertebrae and the articular processes of the fourth to seventh cervical vertebrae

Insertion Spinous processes of all the vertebrae except the atlas

Innervation The posterior rami of the spinal nerves

Action Prime mover for lateral flexion and rotation to the opposite side If both sides act together they are prime movers for extension and hyperextension of the spine

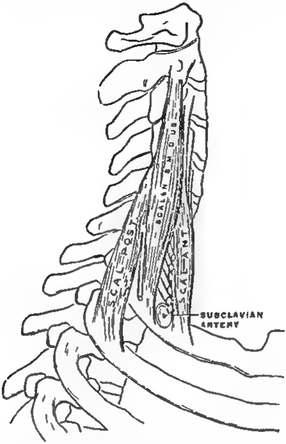

FIG 150—The scaleni (*Gray's Anatomy*)

cervical and first three thoracic vertebrae

Insertion The tubercle on the anterior arch of the atlas the anterior surfaces of the bodies of the second through fourth cervical vertebrae, and the transverse processes of the fifth and sixth cervical vertebrae

Innervation *Branches of the second to seventh cervical nerves*

Action Assistant mover in flexion and lateral flexion of the cervical spine

LONGUS CAPITIS

Origin The anterior tubercles of the transverse processes of the third to sixth cervical vertebrae

Insertion Inferior surface of the basilar part of the occipital bone

Innervation Branches from the first three cervical nerves

Action Assistant mover for flexion and lateral flexion of the head and cervical spine

RECTUS CAPITIS ANTERIOR

Origin Anterior surface of the lateral mass of the atlas and the root of its transverse process

Insertion The inferior surface of the occipital bone anterior to the foramen magnum

Innervation Branches of the first and second cervical nerves

Action Assistant mover for flexion of the head

SEMISPINALIS DORSI

Origin The transverse processes of the sixth to tenth thoracic vertebrae (Fig 151)

Insertion The spinous processes of the four upper thoracic and two lower cervical vertebrae

Innervation Posterior rami of thoracic nerves

Action Prime mover for lateral flexion and rotation to the opposite side If both sides act together, they are prime movers for extension and hyperextension of the spine

SEMISPINALIS CERVICIS

Origin The transverse processes of the upper five or six thoracic vertebrae (Fig 151)

Insertion The spinous processes from the axis to the fifth cervical vertebra

Innervation Posterior rami of the cervical nerves

Action Prime mover for lateral flexion, and rotation to the opposite side If both sides act together they are prime movers for extension and hyperextension of the spine

SEMISPINALIS CAPITIS (COMPLEXUS)

Origin Articular processes of the fourth through sixth cervical vertebrae and the transverse processes of the seventh cervical and first six thoracic vertebrae (Fig 151)

Insertion Between the superior and inferior nuchal lines of the occipital bone

Innervation The posterior rami of the cervical nerves

Action Prime mover for lateral flexion of the head and cervical spine Prime mover for extension and hyperextension of the head and cervical spine when both sides act together

ILIOCOSTALIS LUMBORUM

Origin The back of the sacrospinal aponeurosis medial to the iliac crest and the inner portion of the iliac crest (Fig 151)

Insertion The inferior borders of the angles of the lower six or seven ribs

Innervation Posterior rami of the spinal nerves

Action Prime mover for lateral flexion and rotation to the same side If both sides act together they are prime movers for extension and hyperextension of the spine

ILIOCOSTALIS DORSI

Origin The upper borders of the angles of the last six ribs (Fig 151)

Insertion The upper borders of the angles of the upper six ribs

Innervation Posterior rami of the spinal nerves

Action Prime mover for lateral flexion and rotation to the same side If both sides act together they are prime movers for extension and hyperextension of the spine

ILIOCOSTALIS CERVICIS

Origin The upper borders of the angles of the third to sixth ribs (Fig 151)

Insertion The transverse processes of the fourth to sixth cervical vertebrae

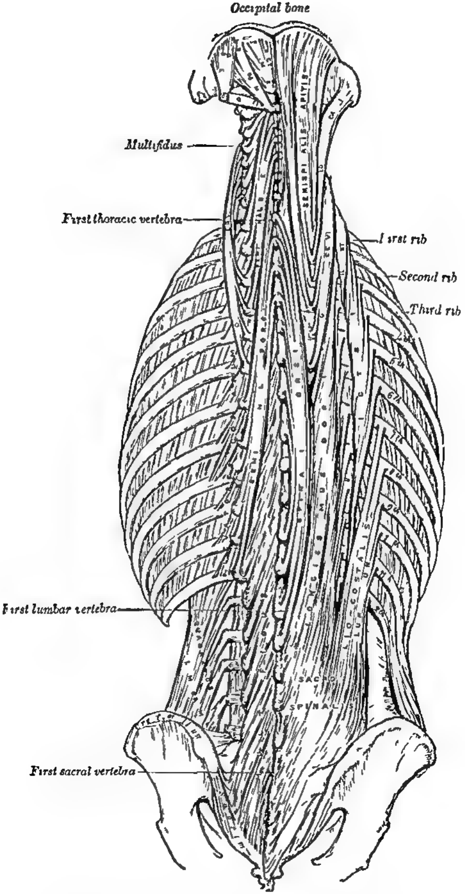

FIG 151 —Deep muscles of the back (*Gray s Anatomy*)

Innervation Posterior rami of the lower cervical nerves

Action Prime mover for lateral flexion If both sides act together, they are prime movers for extension and hyperextension of the spine

SPLENIUS CERVICIS

A broad sheet of muscle whose fibers pass upward and laterally to the cervical spine (Fig 152)

Origin Spinous processes of the third to the sixth thoracic vertebrae

Insertion Transverse processes of the upper two or three cervical vertebrae

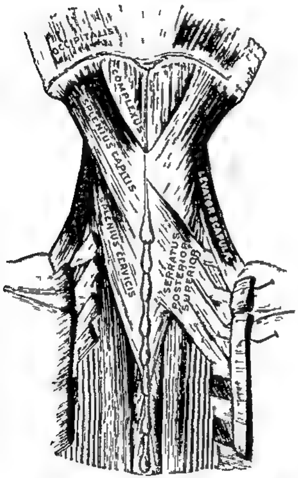

FIG 152 —The splenius and the serratus superior

Innervation Posterior rami of the lower cervical nerves

Action Prime mover for lateral flexion and rotation to the same side If both sides act together they are prime movers for extension and hyperextension of the spine

SPLENIUS CAPITIS

A broad sheet of muscle whose fibers pass upward and laterally to the skull The greater portion of the muscle is covered by the trapezius and it covers the semispinalis capitis (Figs 149 and 152)

Innervation Posterior rami of the spinal nerves

Action Prime mover for lateral flexion and rotation to the same side If both sides act together, they are prime movers for extension and hyperextension of the spine

LONGISSIMUS DORSI

Origin By the sacrospinal aponeurosis to the posterior aspects of the sacrum the spines of the lumbar vertebrae and the iliac crest (Fig 151)

Insertion Accessory processes of the first to the fifth lumbar vertebrae transverse processes of the first thoracic to the fifth lumbar vertebrae and into the second to twelfth ribs between their tubercles and angles

Innervation Posterior rami of the spinal nerves

Action Prime mover for lateral flexion and rotation to the same side If both sides act together they are prime movers for extension and hyperextension of the spine

LONGISSIMUS CERVICIS

Origin The transverse processes of the first four to six thoracic vertebrae (Fig 151)

Insertion The transverse processes of the second to sixth cervical vertebrae

Innervation Posterior rami of the spinal nerves

Action Prime mover for lateral flexion and rotation to the same side If both sides act together they are prime movers for extension and hyperextension of the spine

LONGISSIMUS CAPITIS

Origin The transverse processes of the first four thoracic and the articular processes of the last four cervical vertebrae (Fig 151)

Insertion Mastoid process of the skull

Innervation The posterior rami of the spinal nerves

Action Prime mover for rotation of the head, and lateral flexion of the head and cervical spine Prime mover for extension and hyperextension of the head when both sides act together

SPINALIS DORSI

Origin The spines of the first two lumbar and last two thoracic vertebrae (Fig 151)

Insertion The spines of the upper thoracic vertebrae the number varying from four to eight

Innervation Posterior rami of the spinal nerves

Action Prime mover for lateral flexion If both sides act together they are prime movers for extension and hyperextension of the spine

SPINALIS CERVICIS

This muscle is often absent

Origin Lower part of the ligamentum nuchae spinous process of the seventh cervical vertebra and sometimes from the spinous processes of the first and second thoracic vertebrae

Insertion The spinous process of the axis and occasionally the spinous processes of the second and third cervical vertebrae

which momentary perfect balance is assumed a voluntary spinal movement in any direction is initiated by momentary concentric contraction of the movers for that joint action With equilibrium thus destroyed gravitational force enters as the prime mover for continuance of the movement that is the trunk tends to fall in that direction In the fraction of a second that the gravitational movement commences the muscles antagonistic to the movement spring into action contracting eccentrically to modify or brake the gravitational acceleration and to lower the trunk under control in the desired direction As the movement continues, the eccentrically contracting muscles are elongated until ligaments (and sometimes also fascial bands) become taut If the momentum of the movement is sufficiently great, these ligaments may be torn but usually they are strong enough to absorb the stress and to stop the movement At the point at which ligaments take over the stresses of gravity, the muscles relax and the individual s torso may literally hang from his intervertebral ligaments A small amount of further motion may be possible if the prime movers for the particular joint action contract strongly and force the ligaments to extend slightly

From the position of trunk flexion the return to the erect position is begun by extension of the hip joint initiated by the muscles of the buttocks and legs In dead lifting (the derrick lift) the lifting effort is usually accompanied by contraction of the gastrocnemius and soleus with a resultant tendency for the heels to rise from the ground This tendency is counterbalanced by an opposing moment produced by the body weight It has been suggested[6] that in most practical lifting operations the maximum lifting force is limited by the maximum counterbalancing moment which the body weight can provide, and that only in exceptional cases will the muscular strength of the trunk extensors be the limiting factor Body proportions may also be of some importance

The common industrial injury to the back is usually a simple myofascial sprain but a suddenly increased stress such as is encountered in lifting a weight in this position may rupture the annulus fibrosus (a double crescent of fibrocartilage quite similar to the meniscus of the knee) or other intervertebral ligaments This probably accounts for many of the injuries to the back experienced by industrial workers Many weight trainers utilize a springy platform known as a hopper to reduce the danger of back injuries while performing dead lifts

It has been estimated however that between 80 and 90 per cent of all backaches result from faulty mechanical and postural habits [7] These aggravate lumbar and sacral structures by placing them under relatively mild but continuous stress Probably most of these trace to a continued mild overstretching of the ligaments and muscles involved

Long Sitting Position In this position the knees are extended so that the calf and hamstring muscles are flat against the floor and the trunk is held perpendicularly erect So long as the hands are *not* placed on the floor to help support the trunk this position cannot be held passively but requires marked static contraction of several muscle groups The taut hamstrings tend to tilt the pelvis backward this tendency must be counteracted by static contraction of hip flexors and abdominal muscles The downward pull of the abdominals on the rib cage tends to flex the thoracic spine this tendency must be counteracted by marked static contraction of the extensors of the thoracic spine

Origin The lower half of the ligamentum nuchae and the spinous processes of the seventh cervical and the upper three or four thoracic vertebrae

Insertion Occipital bone and mastoid process of the temporal bone

Innervation Lateral branches of the posterior rami of the middle and lower cervical nerves

Action Prime mover for rotation to the same side and lateral flexion of the head and cervical spine Prime mover for extension and hyperextension of the head and cervical spine when both sides act together

SUBOCCIPITAL MUSCLES

Four muscles rectus capitis posterior major, rectus capitis posterior minor obliquus capitis superior and obliquus capitis inferior (Fig 151)

Origin Posterior surfaces of the atlas and axis

Insertion The first three deep on the occipital bones the last, the transverse process of the atlas

Innervation Branches of the suboccipital nerve

Action Assistant movers for lateral flexion of the head and for rotation of the head to the same side Assistant movers for extension and hyperextension of the head when both sides act together

MOVEMENTS OF THE TRUNK

The muscles of the spine occur in pairs placed in bilateral symmetry Lateral stability is maintained by intermittent contraction of the muscles each side of the center line with the muscles of one side counteracting any tendency to fall toward the opposite side The quadratus lumborum internal and external obliques and erector spinae group are the main lateral stabilizers Undesired extension of the spine is prevented by contraction of the abdominal group Electromyographic studies[3 4 5] have confirmed this pattern of postural stabilization with intermittent and finely graduated contractions appearing to be correlated with body sway Erect posture is not a firm rigid position but the result of a precisely integrated series of continuous dynamic adjustments which are appropriately graded by the feedback from kinesthetic sensations originating in muscles ligaments, tendons labyrinths and occulo motor apparatus

Erect Standing Position The problem of stabilizing the body at the spinal joints is more difficult than is the problem of stabilizing it at the knee and hip joints The fact that there are two lower limbs to act as weight bearing extremities simplifies the stabilization of the body in the lateral plane The spine is a single weight bearing column which depends entirely upon muscular strength for both lateral and anterior posterior stabilization The knee and hip joints may be locked in slight hyperextension allowing the small gravitational torques tending to destroy balance to be borne by the ligaments but in the spine the joints cannot be locked and the normal antero posterior curves are constantly subject to gravitational torques which tend to increase them and thus destroy upright stability If the spinal muscles are weak or if they lack endurance curvature in any direction may increase markedly and ligaments may be subject to acute or chronic stresses These excessive curvatures become pathological in geometric proportion to their extent

Movements from Standing Position From an erect standing position in

springs into action simultaneously with the sterno cleido mastoid The oblique abdominals come into action almost immediately afterwards as the curl is continued, but the intensity of their activity never approaches that of the recti[3] unless exceptional resistance is encountered The curl is valuable because it activates abdominals without requiring significant activity in the hip flexors Walters[8] demonstrated greater activity in the *upper* portions of the rectus abdominis when no resistance other than body weight was employed but an equal activity in upper and lower portions when an extra 10-pound weight was harnessed to the shoulders

The Reverse Trunk Curl In this exercise, knees and hips are flexed and knees are drawn toward the chest so that the curl commences at the lower spinal levels All abdominals are active, and Walters'[8] experiment showed that activity was greater in the lower portions of the rectus abdominis than in the upper portions There is reason to believe that the obliques are more active in reverse curls than in regular curls Because of the flexed knees and hips the hip flexors do not encounter great resistance in reverse curls The amount of resistance to contraction of the abdominals may be increased by performing reverse curls from a position of hanging by the hands from a bar

Double Leg Raising Raising the straight legs requires contraction of abdominals against strong resistance but the contraction tends to be static Hip flexion predominates over spine flexion making the exercise better suited for developing the ilio psoas than the abdominals In weaker individuals the abdominals may be unable to stabilize the pelvis, and lumbar hyperextension may actually be increased

Single Leg Raising Muscle contraction is similar to that involved in double leg raising except that the intensity of activity is much less The abdominal muscles on the same side as the lifted leg are more active than their opposite counterparts, and the internal oblique is more active than the other abdominals [3]

Double Leg Circling This exercise starts from supine lying position with knees drawn up to the chest The legs are dropped to one side knees and hips are extended and the legs are circled through long lying position around to the opposite side whereupon hips and knees are again flexed and returned to starting position The pattern of muscular contraction is almost opposite to that of regular trunk curls—although all abdominals contract the external oblique is markedly more active than the rectus abdominus The long lever of the extended legs offers considerable resistance to the ilio psoas

Situps The complete situp adds an important hip flexion phase to trunk curling There is little reason to believe that the whole situp *is superior* to trunk curls from the standpoint of abdominal development since an emphasis upon contraction of the ilio psoas is usually considered undesirable However, Walters[8] has shown electromyographically that the abdominals are involved more and more strongly as the starting position is changed *from long lying* to hook lying and that the hip flexors become less and less active Whether in long lying or hook lying position the activity of the hip flexors is increased when the feet are held down and the activity of the abdominals is increased when they are not held down

Arm flinging makes it easier to perform situps because the momentum of the arms is transferred to the trunk substituting for contraction of hip

While holding the position, the hamstrings lumbar spine extensors and thoracic spine flexors are being stretched Thus the position has general postural corrective values

Hook Sitting Position This is similar to long sitting position, except that the knees are flexed and the heels are drawn up toward the buttocks, with soles flat on the floor The knee flexion removes almost all tension in the ham strings and the hip flexion slackens the ilio psoas so much that it is unable to shorten sufficiently to pull on the pelvis Therefore, the pelvis assumes a natural backward tilt, being restrained only by the stretched rectus femoris The lumbar curve tends to be obliterated under the influence of static con traction in the abdominals, which are contracting in order to hold the truck erect The abdominals pull downward on the rib cage necessitating contrac tion of the extensors of the thoracic spine Compared to long sitting position the hook sitting position has the additional value of eliminating activity by the ilio psoas and of providing a greater stretch for the lumbar spine extensors

Long Lying Position, Supine With the knees hips and spine extended in this position gravity tends to eliminate or minimize all spinal curves The ilio psoas and the Y ligament are moderately stretched as are lumbar spine extensors thoracic spine flexors and shoulder girdle abductors Circulatory stasis in the great veins of the lower extremity and abdominal cavity is dis couraged, because the return of venous blood to the heart is much easier in the horizontal position

The great disadvantage of the long lying position results from the stretch which is applied to the ilio psoas and the Y ligament In the individual who has excessive lumbar curvature (lordosis), the tension in the ilio psoas and the Y ligament combines with the tension produced by the short lumbar extensor muscles to cause forward pelvic tilt Gravity may only partly remedy this and in some individuals there may be up to 4 inches or more of vertical space between the floor and the highest point in the lumbar curve Such excessive curvature elongates and stretches the abdominals and may make it impossible to perform curling situps In milder cases of lumbar curvature voluntary contraction of the abdominal muscles may be sufficient to flatten the lumbar curve Such lumbar flattening (or backward pelvic tilt) is itself a good correc tive exercise since the abdominals are strengthened while the lumbar extensors and ilio psoas are stretched

Hook Lying Position This is similar to long lying position, except that the knees are flexed and the heels are drawn up toward the buttocks with soles flat on the floor The hook lying position has all the advantages of the long lying position without the undesirable tension on the hamstrings ilio psoas and Y ligament which are made slack by the knee and hip flexion The hook lying position when used as a starting or terminal position for exercise eliminates the hip flexors from the activity provided that the legs are not held down by a partner strap or other apparatus [8]

ANALYSIS OF MOVEMENTS IN TRUNK EXERCISES

The Trunk Curl From the long lying position supine a trunk curl com mencing at the upper levels of the spine will carry the trunk about one third of the way toward the sitting position (The rest of the situp consists primarily of hip flexion) As the head is lifted at the start of the curl the rectus abdominis

in weight lifting and pyramid building where loads may be attempted which are too heavy for the muscles to tolerate These injuries are very painful, slow to heal, and extremely liable to recurrence The victim will complain that there is no position which he can assume with comfort Usually the erector spinae muscle group is the one injured, occasionally the quadratus lumborum may be involved Injuries of this type are commonly referred to as sacro iliac strains, actually the construction of the bony framework of that area suggests that it is almost impossible to *injure it in the course* of normal activity Probably most back injuries incurred in athletics are actually in the lumbo sacral area The application of heat and supportive adhesive strapping or supportive belts to the affected area will give relief

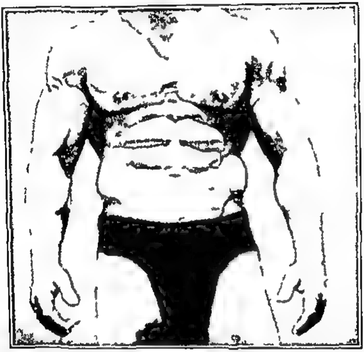

FIG 153 —Abdominal muscles of Bob Hinds The development of the external obliques is unusual and is seen only in individuals who have exercised these muscles vigorously over a long period In early physical training literature such hypertrophied external obliques were often referred to by the poetic name Girdle of Apollo (Courtesy Rader)

In instances in which an individual complains of low back pain without the occurrence of an injury the kinesiologist should carefully examine the length of the legs and the height of the iliac crests to determine whether they are even If they are not this may be the source of the difficulty

Strong abdominal musculature is necessary to resist successfully blows which might otherwise reach the vital organs At the least such blows may cause an interruption in respiration as in the solar plexus punch at worst they may cause hemorrhage or an actual lesion in one of the underlying organs The fact that these muscles are so little employed in ordinary activity necessitates the use of very specific exercises In many cases the exerciser works the frontal muscles to a satisfactory degree but overlooks the fact that the side

and spine flexors If the object is to sit up with the least expenditure of energy, arm flinging should be employed if the object is development of muscles it should be eliminated

A trunk twist may be added to the situp exercise touching one hand to the opposite foot after the situp is complete Walters[8] suggests that this twisting causes no extra activity in the external obliques and that it is performed almost entirely by the internal obliques The situation may be different if the twist is especially vigorous, as in touching one *elbow* to the opposite *knee* while fingers are clasped behind the neck Resistance to such a twist is so great that one would expect all of the trunk rotators to participate

ACTION OF THE PSOAS ON THE SPINE

The psoas is primarily a flexor of the hip, although it is also listed as a flexor of the lumbar spine The use of an articulated skeleton to study its origin and angle of pull is recommended since two dimensional drawings may be misleading

Under special circumstances the psoas may become a *hyperextensor* of the lumbar spine This reversal of function is sometimes called the *psoas paradox* It generally occurs when the body is in supine lying position As the psoas contracts it is joined by the iliacus in flexing the hip joint and it tends to pull on the lumbar vertebrae in an anterior and inferior direction If the abdominals contract simultaneously forward tilt of the pelvis is prevented and lumbar flexion and/or hip flexion will result But if the abdominals are weak the pelvis tilts forward under influence of the iliacus while the lumbar vertebrae are raised off the floor (lumbar hyperextension) by the psoas The passive weight of the head and thorax prevent the trunk from flexing in response to the pull of the psoas

Adequate contraction of the abdominals would prevent the psoas from hyperextending the lumbar spine but there is a fairly consistent tendency for abdominal strength to be inferior functionally to psoas strength Furthermore, the human body tends to have pre existing excessive lumbar curvature of an inflexible nature Therefore it is a principle of general therapeutic and conditioning exercise to emphasize abdominal development and to minimize ilio psoas development in an attempt to achieve a better balance between the two muscle groups Many proposed abdominal exercises such as double leg lifting activate the paradoxical function of the psoas as a lumbar spine hyperextensor and cause unwarranted stretch and stress in the abdominals

Probably it is advisable for all people to avoid psoas exercises but it is particularly important for the weaker or undervitalized individual to do so If when attempting an exercise that calls for flexion of the lumbar spine, an individual s first effort is accompanied by lumbar hyperextension that exercise is contra indicated

Implications for Athletic Training A supporting column is normally rigid in the human spine however nature has sacrificed rigidity in order to secure a relatively wide range of movement The result of this attempt to combine two incompatible qualities is an unstable structure which may be seriously deranged by sports as diverse as golf and weight lifting Back injuries are particularly common in sports such as wrestling trampoline diving and pole vaulting in which strong rotational movements of the back are frequent and

8 What are the advantages or disadvantages of doing situps on a bench so that the movement is started with the head lower than the hips?

9 Toe touching from the erect position is sometimes recommended for the development of the abdominal musculature Analyze the value of this recommendation

10 Have a subject lie supine on a bench Have another student straddle the bench and hold the subject s hips firmly in contact with it Instruct the subject to sit up Measure the angle through which he can move

11 Spinal rotation is named right or left according to the direction in which the face is turned If the upper part of the spine is stabilized and the lower part of the spine is turned, the rotation is called right or left according to which direction the face would have turned had it been the moving part Specify the direction of spinal rotation in the following exercises

(a) From erect standing position, turn head and shoulders to the left

(b) From a position of hanging by the hands from a bar, turn the pelvis and legs to the left

(c) From supine lying with legs raised to vertical lower both legs sideways left to the floor while keeping the shoulders flat on the floor

12 Analyze various spinal column exercises according to the following schema Exercise—*Starting Position* Supine lying hands on top of thighs palms down *Movement* Curl up starting with the upper spine until the fingertips cover the knee-caps

Exercise	*Curl up*				
Left rectus abdominis	C				
Right rectus abdominis	C				
Left external oblique	C				
Right external oblique	C				
Left internal oblique	C				
Right internal oblique	C				
Left quadratus lumborum	R or S				
Right quadratus lumborum	R or S				
Left sacrospinalis group	R				
Right sacrospinalis group	R				
Left deep back	R				
Right deep back	R				

R = relaxed
C = concentric contraction
E = eccentric contraction
S = static contraction

muscles need equally vigorous training Major ruptures of the abdominal wall as sometimes result from pushing throwing or boxing require surgical repair

The question of whether the development of the abdominal musculature aids in the prevention of hernia is a matter for argument In the opinion of some surgeons hernia results from an innate defect in the abdominal wall and it seems unlikely that any appreciable benefit is derived from preventive exercises On the other hand many therapists with a good deal of experience with exercise are convinced that abdominal development contributes to the prevention of this condition The answer probably lies in the cause of the individual injury

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LABORATORY EXERCISES

1 The layman often includes toe touching from the erect position in his Daily Dozen routine in the belief that it strengthens the muscle of the back Make an analysis of the kinesiology of this exercise Why do many kinesiologists believe that its practice contributes to poor posture?

2 Weight trainers sometimes place a heavy barbell on their shoulders and then twist the trunk alternately to the right and the left What is the danger of this exercise?

3 Analyze the differences in the function of the spine in an erect biped and in a quadruped

4 What sort of exercises might be recommended for a person known to be subject to low back disability?

5 What would be the difference in muscular development achieved through practice of the wrestler s bridge in the supine poistion as compared with practice of it in the prone position?

6 What are the disadvantages to sleeping in an excessively soft bed? Why is a person with a back injury more comfortable on a firm surface than on a yielding one?

7 Compare the effects of leg raising and situps on the floor with those of the same exercise done on an inclined board

8 What are the advantages or disadvantages of doing situps on a bench so that the movement is started with the head lower than the hips?

9 Toe touching from the erect position is sometimes recommended for the development of the abdominal musculature Analyze the value of this recommendation

10 Have a subject lie supine on a bench Have another student straddle the bench and hold the subject s hips firmly in contact with it Instruct the subject to sit up Measure the angle through which he can move

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Exercise	*Curl up*				
Left rectus abdominis	C				
Right rectus abdominis	C				
Left external oblique	C				
Right external oblique	C				
Left internal oblique	C				
Right internal oblique	C				
Left quadratus lumborum	R or S				
Right quadratus lumborum	R or S				
Left sacrospinalis group	R				
Right sacrospinalis group	R				
Left deep back	R				
Right deep back	R				

R = relaxed
C = concentric contraction
E = eccentric contraction
S = static contraction

TABLE 14 —Spinal Muscles and Their Actions

Muscles	Flexion	Extension	Lateral flexion	Rotation to the same side	Rotation to the opposite side
CERVICAL SPINE					
Sterno cleido mastoid	P M		P M		P M
The 3 scaleni	Asst		P M		
The prevertebral muscles (Longus colli longus capitis rectus capitis anterior rectus capitis lateralis)	Asst		Asst		
Splenius capitis and splenius cervicis		P M	P M	P M	
The sacrospinalis or erector spinae (Iliocostalis cervicis longissimus cervicis longissimus capitis and spinalis cervicis)		P M	P M	P M	
Semispinalis cervicis		P M	P M	P M	
Semispinalis capitis		P M	P M		
The deep posterior spinal muscles					
Intertransversarii		P M	P M		
Interspinales		P M			
Rotatores		P M			P M
Multifidus		P M	P M		P M
The suboccipital muscles		Asst	Asst	Asst	
THORACIC AND LUMBAR SPINES					
The abdominal muscles					
Rectus abdominis	P M		Asst		
External oblique	P M		P M		P M
Internal oblique	P M		P M	P M	
Psoas	Asst	Asst *			
Quadratus lumborum			P M		
The sacrospinalis or erector spinae					
Iliocostalis dorsi		P M	P M	P M	
Iliocostalis lumborum		P M	P M	P M	
Longissimus dorsi		P M	P M	P M	
Spinalis dorsi		P M	P M		
Semispinalis dorsi		P M	P M		P M
The deep posterior spinal muscles					
Intertransversarii		P M	P M		
Interspinales		P M			
Rotatores		P M			P M
Multifidus		P M	P M		P M

* Under special circumstances (which are described in the text) the psoas may become a hyperextensor of the lumbar spine The iliacus may contribute to this action indirectly by tilting the pelvis forward

Chapter 17

Muscles of the Thorax and Respiration

The framework of the thorax includes the twelve thoracic vertebrae, twelve pairs of ribs, the costal cartilages, and the sternum. The *head* of each rib articulates with the body of the similarly numbered thoracic vertebra by means of a synovial joint with a ligamentous capsule, and (except for the first, tenth, eleventh, and twelfth ribs) with the body of the thoracic vertebra immediately above. Each rib has a *tubercle* which makes a synovial articulation with the tip of the transverse process of its own vertebra. The part between the head and the tubercle is called the *neck*. The remainder of the rib is the long curving *shaft*, and its point of sharpest curvature is called the *angle*. The ends of the ribs are continuous with the costal cartilages. These hyaline bars are normal epiphyseal cartilage. They may ossify partially or completely after puberty. The first seven costal cartilages join the sternum either directly or by means of an interposed synovial joint. The eighth through tenth costal cartilages do not join the sternum, but are continuous with the costal cartilage immediately above. The eleventh and twelfth costal cartilages are free; their ribs are known as "floating ribs." The sternum is made up of three parts, named from above down: the *manubrium*, the *body*, and the *xiphoid process*. They are joined by epiphyseal cartilages which do not ossify until after middle age. In youth, the body has four parts separated by epiphyseal cartilages.

The ribs may be raised and lowered by means of motion in the synovial articulations with the vertebrae; in addition, the thin shafts, the costal cartilages, and the sternum are rather markedly deformable. The sum of these possible movements is appreciable. Rib cage movements are usually considered as a whole and are called *elevation* and *depression* (Fig. 154). The movements of elevation and depression should not be confused with the general raising and lowering of the entire thorax caused by extension and flexion of the thoracic spine. Likewise, adduction of the shoulder girdle gives the appearance of chest expansion which should not be confused with true movements of the rib cage. Technically, elevation and depression of the rib cage occur only in conjunction with breathing movements.

Breathing is the flow of air in or out of the lungs (inspiration and expiration)

associated with elevation and depression of the rib cage and with the descent and return of the floor of the thorax resulting from contraction and relaxation of the diaphram muscle.

Within the rib cage are the right and left *pleural cavities* separated medially by the mediastinum, a partition containing the heart in its pericardial sac, blood vessels, nerves, lymph vessels, thymus gland, esophagus, trachea and bronchi, connective tissue, and the two lungs. The lungs may be thought of as having grown out of the mediastinum and invaded the right and left pleural cavities until the cavities are obliterated by the pushing of their medial walls against their lateral walls. Thus the pleural cavities have no air space within them, but only potential spaces containing a slight amount of fluid. Actually the idea of the lungs "pushing outward" is false, for the lungs have a marked elasticity which constantly tends to make them contract or shrivel. Since the pleural cavities are completely self-inclosed, air cannot enter them, and their

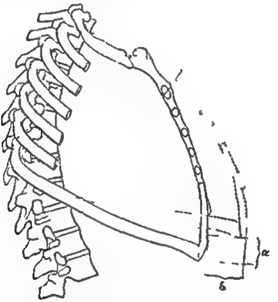

FIG. 154.—Enlargement of the chest by elevation of the ribs.

slight negative pressure (loosely called a "partial vacuum") allows the atmospheric pressure of air in the lungs to overcome the natural contractile tendency of the lungs and to push the walls of the lungs outward against the rib cage, virtually obliterating the pleural cavities. If the thorax is punctured from the outside, air rushes into the pleural cavity until atmospheric pressure is established, equalling the atmospheric pressure of the air within the lungs. Because the natural elasticity of the lungs is now unopposed, the lung shrivels *up around its root in the mediastinum*.

During inspiration the ribs are elevated, enlarging the antero-posterior diameter of the thorax (Fig. 154). The shafts of the ribs, especially the lower ones, also move laterally, increasing the lateral thoracic diameter. Simultaneously the dome-shaped diaphragm contracts and flattens the floor of the thorax, increasing the vertical diameter. With the thoracic volume thus enlarged, atmospheric pressure causes air to enter the lungs and expand them.

Muscular contraction, then, is necessary for even the smallest amount of inspiration

At resting levels of breathing no muscular contraction is necessary for expiration The muscles relax and the weight of the thorax causes depression of the ribs The natural elasticity of the lungs draws the diaphragm back up to its domed position, with the assistance of pressure caused by the residual resting tension in the muscles and connective tissues of the abdominal wall Forced expiration, on the other hand, such as occurs in deep or rapid breathing requires definite contraction of abdominal musculature and of rib cage depressors Modern research has left unchanged this historic concept of breathing mechanisms, although there remains much confusion and doubt about the role of specific muscles

The muscles primarily involved in the respiratory movements include the following

Intercostales Externi
Intercostales Interni
Diaphragm
Levatores Costarum
Serratus Posterior Superior
Transversus Abdominis
Serratus Posterior Inferior

INTERCOSTALES EXTERNI

Eleven sheets of muscular fibers located in the spaces between the ribs (Fig 155)

Origin The lower borders of the first eleven ribs

Insertion The upper borders of the last eleven ribs

Innervation The intercostal nerves

Structure Short parallel fibers extending diagonally forward and downward in the direction of the external oblique They extend from the spinal column forward to the costal cartilages, being absent next to the sternum

Action Although the action of the intercostals has long been a matter of dispute it is now generally agreed that the intercostales externi act to lift the ribs in inspiration with the upper ribs fixed by the scaleni Electromyographic studies indicate that during quiet breathing the intercostal muscles contract only during inspiration but it is possible that they contract strongly during voluntary expiratory efforts and in coughing if the lower ribs are held downward by contraction of the abdominal muscles and the quadratus lumborum [1 2]

INTERCOSTALES INTERNI

Eleven muscular sheets just beneath the intercostales externi (Fig 155)

Origin The ridge on the inner surface of a rib or the corresponding costal cartilage

Insertion The upper border of the rib below

Innervation Intercostal nerves

Structure Short parallel fibers extending diagonally downward and backward opposite in direction to the intercostales externi They commence at the sternum between the true ribs and at the anterior extremities of the cartilages of the false ribs and backward as far as the angles of the ribs

associated with elevation and depression of the rib cage and with the descent and return of the floor of the thorax resulting from contraction and relaxation of the diaphram muscle

Within the rib cage are the right and left *pleural cavities* separated medially by the mediastinum a partition containing the heart in its pericardial sac, blood vessels, nerves lymph vessels, thymus gland esophagus trachea and bronchi, connective tissue, and the two lungs The lungs may be thought of as having grown out of the mediastinum and invaded the right and left pleural cavities until the cavities are obliterated by the pushing of their medial walls against their lateral walls Thus the pleural cavities have no air space within them, but only potential spaces containing a slight amount of fluid Actually the idea of the lungs pushing outward is false for the lungs have a marked elasticity which constantly tends to make them contract or shrivel Since the pleural cavities are completely self inclosed air cannot enter them and their

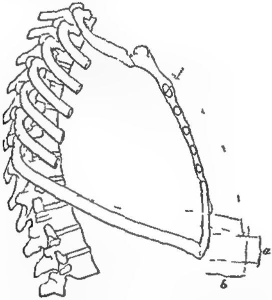

FIG 154 —Enlargement of the chest by elevation of the ribs

slight negative pressure (loosely called a partial vacuum) allows the atmospheric pressure of air in the lungs to overcome the natural contractile tendency of the lungs and to push the walls of the lungs outward against the rib cage virtually obliterating the pleural cavities If the thorax is punctured from the outside air rushes into the pleural cavity until atmospheric pressure is established equalling the atmospheric pressure of the air within the lungs Because the natural elasticity of the lungs is now unopposed the lung shrivels up around its root in the mediastinum

During inspiration the ribs are elevated enlarging the antero posterior diameter of the thorax (Fig 154) The shafts of the ribs especially the lower ones, also move laterally increasing the lateral thoracic diameter Simultaneously, the dome shaped diaphragm contracts and flattens the floor of the thorax increasing the vertical diameter With the thoracic volume thus enlarged atmospheric pressure causes air to enter the lungs and expand them

quiet breathing may be the only respiratory muscle in action [1,3] Contraction of its fibers pulls down on the central tendon and up on the ribs and sternum The ribs are lifted slightly, but the central tendon is depressed as the principal movement In quiet respiration the total diaphragmatic movement is about 1 5 cm , in deep respiration the total diaphragmatic excursion is between 7 and 12 cm [4] In normal breathing there is close cooperation between the movements of the diaphragm and of the intercostales As the diaphragm descends it flattens and creates more room in the chest The relation of the diaphrm to the abdomen as well as to the chest is of importance When it descends it must, of course, displace the abdominal cavity just as much as it adds to the thoracic cavity It pushes the stomach liver, and other abdominal organs before it,

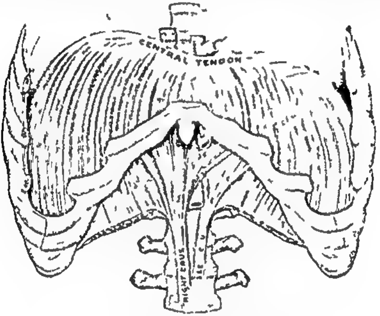

Fig 156—The diaphragm

and since these organs are soft and pliable but not easily compressible they crowd out against the abdominal wall The soft and flexible abdominal wall gives way expanding on the front and somewhat at the side to make the needed room If the abdominal wall is thick and strong it offers considerable resistance to the descent of the diaphragm and this will increase the upward pull of the latter on the ribs

LEVATORES COSTARUM

Twelve small muscles on each side of the spine (Fig 151)

Origin The transverse processes of the last cervical and the first eleven thoracic vertebrae

Insertion The outer surfaces of the ribs between the tubercle and the angle

Innervation Branches of the intercostal nerves

Structure These muscles pass obliquely downward and laterally similar to the external intercostals They insert into the rib beneath except that the lower four divide one part attaching to the rib beneath and the other to the second rib below its origin

Action The action of the intercostales interni, like that of the intercostales externi, is to draw the ribs together Electromyographic studies do not support the distinctions often made between the actions of the external and internal intercostals [2] If the upper ribs are fixed, the action of the intercostales will tend to lift the remaining ribs, if the lower ribs are fixed, the action of the intercostales will tend to depress the remaining ribs

THE DIAPHRAGM

A dome shaped sheet partly muscular and partly tendinous forming a partition between the thoracic and abdominal cavities The tendon is at the summit of the dome and the muscle fibers along the sides (Fig 156)

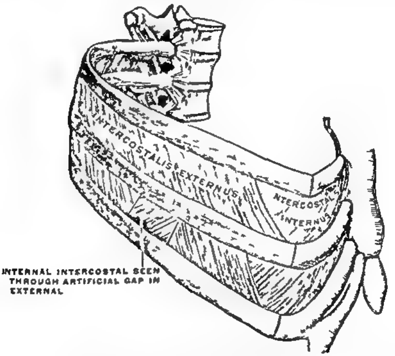

FIG 155 —The intercostal muscles

Origin An approximately circular line passing entirely around the inner surface of the body wall It is attached at the back to the upper two lumbar vertebrae and the lumbar fascia on the sides for a variable distance to the lower two ribs at the front to the six lower costal cartilages and to the sternum

Insertion The central tendon which is an oblong sheet forming the summit of the dome

Innervation The phrenic nerve from the cervical plexus with fibers largely from the fourth but also from the adjacent cervical nerves

Structure The fibers pass vertically upward for some distance from the origin and then turn inward to their insertion The fibers of the sternal portion are shortest the lateral portion has saw toothed attachments to the ribs and cartilages in alternation with those of the transversalis which is a muscle of expiration

Action The diaphragm is the principal muscle of inspiration and during

quiet breathing may be the only respiratory muscle in action [1,3] Contraction of its fibers pulls down on the central tendon and up on the ribs and sternum The ribs are lifted slightly, but the central tendon is depressed as the principal movement In quiet respiration the total diaphragmatic movement is about 1 5 cm in deep respiration the total diaphragmatic excursion is between 7 and 12 cm [4] In normal breathing there is close cooperation between the movements of the diaphragm and of the intercostales As the diaphragm descends it flattens and creates more room in the chest The relation of the diaphragm to the abdomen as well as to the chest is of importance When it descends it must, of course displace the abdominal cavity just as much as it adds to the thoracic cavity It pushes the stomach liver and other abdominal organs before it,

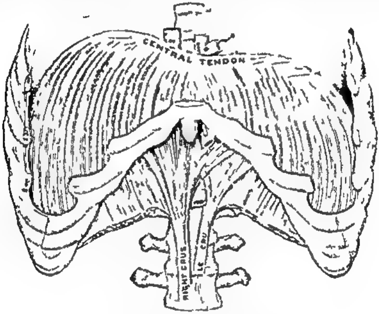

FIG 156—The diaphragm

and since these organs are soft and pliable but not easily compressible, they crowd out against the abdominal wall The soft and flexible abdominal wall gives way expanding on the front and somewhat at the side to make the needed room If the abdominal wall is thick and strong it offers considerable resistance to the descent of the diaphragm and this will increase the upward pull of the latter on the ribs

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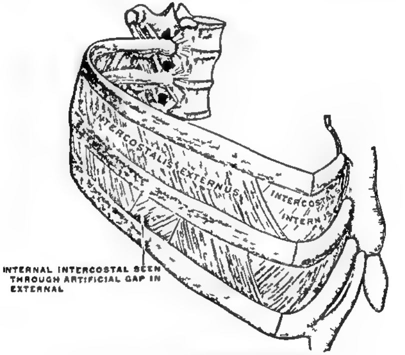

FIG 155 —The intercostal muscles

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Insertion The central tendon which is an oblong sheet forming the summit of the dome

Innervation The phrenic nerve from the cervical plexus with fibers largely from the fourth but also from the adjacent cervical nerves

Structure The fibers pass vertically upward for some distance from the origin and then turn inward to their insertion The fibers of the sternal portion are shortest the lateral portion has saw toothed attachments to the ribs and cartilages in alternation with those of the transversalis which is a muscle of expiration

Action The diaphragm is the principal muscle of inspiration and during

Origin Lateral third of the inguinal ligament, anterior three fourths of the iliac crest, the lumbodorsal fascia and the cartilages of the lower six ribs

Insertion Linea alba

Innervation Branches from the seventh to twelfth intercostal, the ilio hypogastric and ilioinguinal nerves

Structure A thick sheet of parallel fibers crossing the abdomen horizontally Its middle part is thickest and also has the longest fibers Like the internal and external obliques its muscular fibers are placed chiefly at the sides of the abdomen The front tendons of the three fuse to form a single tendon which is slit down the center to form a sheath for the rectus abdominis

Action Constricts the abdomen, compressing the contents and assisting in micturition defecation, emesis, parturition and forced expiration

SERRATUS POSTERIOR INFERIOR

Named from its position and its saw toothed insertion (Fig 71)

Origin The spines of the last two thoracic and the first two or three lumbar vertebrae

Insertion The lower four ribs beyond their angles

Innervation Branches of the anterior rami of the ninth to twelfth thoracic nerves

Structure The inner half is a tendinous sheet blended with the tendons of the latissimus and erector spinae The muscular fibers are inserted directly into the ribs

Action The fibers of the serratus posticus inferior are in a position to depress the ribs and the angle of pull is large It is therefore generally considered a muscle of expiration

ANALYSIS OF RESPIRATORY MOVEMENTS

Although the general nature of breathing movements is well understood, the individual contributions of the specific muscles is still the subject of great disagreement One reason for the confusion is the fact that the conditions of breathing vary from person to person and from situation to situation Individual differences in structure are startling—the number of ribs, the nature of their articulations the general body build of the person and the amount of superincumbent fat are widely variable In females the relative size of the breasts and the occurrence of pregnancy are variables Mobility and flexibility of structures vary with age and degree of ossification of cartilages The chest is relatively deep and narrow in infancy and becomes broadened and flattened as the individual matures, apparently as a result of the normal activity of the body The degree of muscular development and the extent of restriction of movement by postural defects cover a wide range Aside from individual variations it is known that the problem of breathing depends upon upright or recumbent position the load carried on shoulders or arms water pressure during submersion amount of stabilization of the chest required to provide a firm base for arm and shoulder girdle movements external forces produced in crutch walking and contact sports such as wrestling and similar factors Quiet and vigorous breathing are entirely different conditions

Sports writers frequently describe athletes as being barrel chested Actually studies of the thoracic indices of successful competitors indicate

Action No adequate studies of the functions of these muscles in man have been reported [1] Their anatomical position suggests that they raise the ribs increasing the thoracic cavity, and, in the vertebral column cause extension lateral flexion, and slight rotation to the opposite side

SERRATUS POSTERIOR SUPERIOR

A flat rhomboidal sheet of muscular fibers lying beneath the upper half of the scapula (Fig 152)

Origin The ligamentum nuchae and the spinous processes of the seventh cervical and the first three thoracic vertebrae

Insertion The second to the fifth ribs inclusive beyond their angles

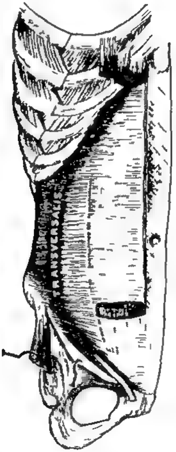

FIG 157—The transversalis

Innervation Branches of the anterior rami of the four upper thoracic nerves

Structure Longitudinal arrangement with the ends tendinous

Action The serratus posticus superior lies so deep beneath the scapula and the trapezius and rhomboid that its action has not been observed Its position and attachments are such that it is able to lift the ribs

TRANSVERSUS ADBOMINIS (TRANSVERSALIS)

This muscle forms the third layer of the abdominal wall next to its inner surface, lying immediately beneath the obliquus internus (Fig 157)

are usually active, that the second intercostals are occasionally active, and that the remaining intercostals are never active As deeper and deeper breaths were taken successive intercostals were recruited, from the top down

Sternomastoid The sternomastoids are important auxiliary muscles of inspiration, provided that the cervical spine is extended and held firm to give them a base to pull upon Their action is to elevate the sternum thus increasing the antero posterior diameter of the thorax However, it is difficult to evaluate the mechanical importance of this They display a surprisingly slight amount of respiratory activity in normal subjects, but become important when the respiratory level is elevated and the ordinary muscles of inspiration are operating at a greatly reduced mechanical advantage [1] Duchenne[11] observed a young male patient with cervical transection of the spinal cord as the result of a fall during the practice of gymnastics who was able to breathe for some weeks by means of his sternomastoids alone

Scaleni Anatomical considerations suggest that the three scaleni have the same fundamental actions Their importance as muscles of respiration is a matter of disagreement Fick is reported to have calculated that potentially they are only one fifth as important as the intercostals [12] Campbell[12] found that they are normally active even during quiet breathing but suggested that they were of importance only during moderately severe voluntary inspiratory efforts and during such procedures as coughing or straining Their action at times may be to fix the upper ribs and prevent the thoracic cage from being pulled downwards by the abdominal muscles or to provide support for the apex of the lung to prevent it from bulging upward

Abdominals During quiet respiration the abdominals are inactive The external and internal obliques (and presumably the transversus, which is inaccessible to or undifferentiated by electromyography) participate vigorously in forced expiration coughing singing straining vomiting and defecation in proportion to the severity of the activity [13, 14] The rectus abdominis is relatively inactive provided that there is no concurrent tendency toward spine flexion [13] The abdominals are considered by Campbell[15] to be the most important muscles of forced expiration His studies demonstrated that in the erect position they do not contract very forcefully until the pulmonary ventilation exceeds 70 to 90 l /min Their effect upon the respiratory system probably reflects the changes of intra abdominal pressure resulting from their contraction and relaxation which in turn affects the position and movement of the diaphragm During quiet breathing the effects of gravity and the elastic recoil of the thoracic cage appear sufficient to produce expiration

Other Muscles The quadratus lumborum and the serratus posterior inferior muscles are often mentioned as assistants in forced expiration as are the serratus posterior superior levatores costarum erector spinae and oblique spine extensors for forced inspiration Their importance is debatable At moments of extreme respiratory distress (dyspnea) the thoracic and cervical spine extensors the thoraco humeral muscles such as the pectoralis major and the thoraco scapular muscles such as the serratus anterior may be effectively utilized to stabilize the spine and keep the rib cage in an elevated position

The rationale for the utilization of this is based on Wade s[4] discovery that chest circumference is increased at the beginning of forced breathing and

that they show a tendency toward wide flat chests rather than round ones [5, 6] According to Seltzer,[7] in exhausting work the flat chested individuals display greater capacities for supplying oxygen to the tissues, indicative of more efficient respiratory and cardiovascular mechanisms There is little to indicate that the successful athlete needs an unusually large chest The vital capacity in most of the runners participating in the 1924 Boston marathon was found to be normal,[8] and the pulmonary functions of the 1956 United States Olympic Free Style Wrestlers did not significantly exceed the norms for young men of similar stature [9] It has been suggested that the respiratory superiority of the trained athlete lies in his greater ability to utilize his maximal lung capacity [10]

Diaphragm The diaphragm is the single most important muscle of inspiration *The flattening of its dome during inspiration is probably responsible for* the greater part of the tidal volume during normal inspiration In normal subjects it is invariably active during inspiration and in some subjects may be the only respiratory muscle active during quiet breathing However, it is not essential, and respiration can go on unhindered even when it is paralyzed The blow which knocks the wind out probably paralyzes and causes temporary spasm of the diaphragm In the trained athlete the diaphragm plays a relatively larger role in respiration than it does in the untrained man This enables him to avoid the muscular fatigue which accompanies the enlargement of the chest wall characteristic of costal breathing There is a theory that women are naturally inclined to costal breathing as a preparation for the time that movements of the diaphragm will be hindered by the processes of pregnancy but if this condition exists it may merely reflect a lack of vigorous athletic training during youth The use of corsets or any wide tight belt about the abdomen is likely to hinder the movements of the diaphragm and force the individual to assume an inefficient costal breathing style

Intercostals As has been indicated earlier in this chapter, the function of the intercostals has been a matter of dispute and their mechanical action is yet to be definitely established *Most anatomy and kinesiology* textbooks state that the external intercostals and the intercartilaginous portions of the internal intercostals function in inspiration and that the interosseous portions of the internal intercostals function in forced expiration The most recent studies indicate that the external intercostals are probably second only to the diaphragm in importance as inspiratory muscles Even the most advanced electromyographical techniques[2] using sensitive needle electrodes inserted deep within the muscles have been unable to distinguish between external and internal intercostal activity and have failed to show any intercostal activity during expiration throwing doubt upon the common textbook explanations

It is questionable whether the internal intercostals normally have any important respiratory function but it should be noted that Duchenne[11] reported a case in which a subject with paralysis of the diaphragm and stenocleidomastoids and with the scalenes about two thirds wasted away continued to breathe by use of the intercostals alone Since the intercostals tend to pull the adjacent ribs together, they may function differently depending upon whether the upper or the lower ribs are stabilized Koepke and his associates[3] have demonstrated that the diaphragm is always active and is the first muscle to come into action in quiet breathing that the first intercostals

qualification except for corrective purposes,' and it is probable that the values of deliberate breathing in some exercise circumstances have been under emphasized

In the absence of physiological or kinesiological needs, taking voluntary deep breaths as an arbitrary exercise is valueless Further many coaches and exercise physiologists are convinced that conscious attempts by athletes to regulate breathing usually interfere with performance Ordinarily, deep breathing is useful only when it results from the stimulation of the breathing mechanisms by hard work Nevertheless voluntary regulation may be warranted under certain circumstances some of which are listed below

(1) After voluntary hyperventilation the breath can be held longer, yielding an advantage in competitive swimming and underwater recreation

(2) Taking a deep breath tends to improve general posture, and may facilitate the learning of optimal postural positions

(3) The correction of various chest deformities such as chicken breast and funnel chest may be aided by maximal inspirations which are inefficiently achieved through natural activities

(4) The undesirable tendency to strain (known as the *Valsalva effect*—an expiratory effort with the glottis closed) while doing heavy work can be prevented only by conscious attention to continuous breathing Some gymnasts participating in arm supporting events exhibit repeated Valsalva effects and are unable to complete their routines unless they are taught to breathe consciously throughout their event

(5) The accuracy of precise movements such as free throwing in basketball and pistol shooting may be increased if the breath is held and the rib case is stabilized at the end of the last normal inspiration preceding the performance

(6) Singers and speakers are taught to maintain a high chest position primarily because the expanded chest serves better as a sounding box and permits longer intervals between inspirations

(7) Those who must talk loudly in their occupation can improve the quality of their voices by taking preliminary deep breaths and by huffing out an unusual amount of air Failure to do this may cause a feeling of strain of the vocal cords

Cost of Ventilation The cost of resting breathing has been estimated to be about 5 ml of oxygen per liter of ventilation The mechanical efficiency is about 3 to 7 per cent which indicates that most of the energy developed by the breathing muscles appears in the form of heat In muscular exercise ventilation usually bears an approximately linear relationship to the oxygen consumption until the steady state is exceeded when pulmonary ventilation becomes excessive Under a work load the cost of voluntary ventilation may exceed 2 ml of oxygen per liter of ventilation At high rates of breathing the oxygen requirement for ventilation becomes a significant proportion of the total consumption hyperventilation is accompanied by little increase in actual pulmonary ventilation This may reflect a decrease in the mechanical efficiency of breathing an increase in the mechanical work required per unit of ventilation or muscular effort *not directly* associated with respiratory movements It has been suggested that the men who have run the mile in under four minutes probably possess a unique ability to achieve a large ventilation volume at a relatively small cost [17, 18]

that subsequent thoracic movements are relatively small around this position This suggested to him that an expanded chest position increases the effective area of the diaphragm, thereby improving ventilation This finding confirms the importance of keeping the thorax high and free from hindrance during severe exercise and recovery Runners for example, should avoid restricted arm movements and excessive tension in the musculature of arms and shoulder girdle

Grasping some supporting object particularly one overhead, after vigorous exertion permits the thoraco humeral muscles to relieve the inertia of the arms and thus reduce the resistance against which the respiratory muscles must act Teammates who assist a staggering runner after his race should throw his arms over their shoulders and let him continue to walk while his shoulder girdle is kept high In this way forced breathing is facilitated (and the continued attempts at voluntary locomotion will help maintain adequate return of venous blood to the heart) If the exhausted athlete collapses he should be placed in supine lying position with his arms in complete abduction, so that the stretched pectoralis major will help to keep the rib cage elevated and the taut sternomastoids can effectively participate in breathing movements

Some athletic coaches, physical educators dramatic coaches, and teachers of singing have distinguished between predominantly thoracic or costal breathing and predominantly abdominal breathing apparently assuming that one type may be better than the other and that a person may learn to emphasize one or the other voluntarily Wade[4] studied a physiotherapist a teacher of singing and two patients who claimed to be able to take breaths which were primarily diaphragmatic or primarily thoracic These subjects could control the amount of protrusion retraction of the abdominal wall and the amount of lifting of the thoracic cage but these differences did not affect the excursion of the diaphragm He concluded that although there is voluntary control over the depth and rate of breathing movements, there is no voluntary control over the diaphragm as an individual muscle In normal subjects excursion of the diaphragm is governed exclusively by the depth of breathing Campbell[1] found no convincing differences in the activity of the intercostal muscles in the two types of breathing Thoracic cage movements may indeed be regulated voluntarily but much of the observed elevation of the rib cage is a product of extension of the thoracic spine a movement which lifts not only the ribs but also the diaphragm thus contributing no extra intrathoracic volume

Breathing exercises The nineteenth century gymnastic systems included deep breathing exercises in the Day s Order the rationale being based on the incomplete and faulty physiological knowledge of the previous century Haphazard early American variations destroyed whatever postural benefit might have been involved in these exercises Williams in his early editions of *Principles of Physical Education* was almost single handedly responsible for popularizing the viewpoint that except for corrective purposes in defective cases breathing exercises are unscientific and probably harmful [16] Williams view was based primarily on the facts that increased ventilation upset the normal partial pressures of blood gases and that effective gas exchange results from physiological needs rather than from increased ventilation Physical educators were so impressed that they tended to ignore the

10 Morehouse Laurence E and Miller, Augustus T, Jr *Physiology of Exercise*, 3rd Ed St Louis The C V Mosby Co 1959 p 152

11 Duchenne G B *Physiology of Motion* translated and edited by Emanuel B Kaplan Philadelphia J B Lippincott Co 1949 pp 469 and 481–485

12 Campbell E J M The Role of the Scalene and Sternomastoid Muscles in Breathing in Normal Subjects An Electromyographic Study J Anat *89* 378–386 1955

13 Floyd, W F and Silver, P O Electromyographic Study of Patterns of Activity of the Anterior Abdominal Wall in Man J Anat *84* 132–145 1950

14 Campbell E J M An Electromyographic Study of the Role of the Abdominal Muscles in Breathing J Physiol *117* 222–223 1952

15 Campbell, E J M and Green J H The Behavior of the Abdominal Muscles and the Intra Abdominal Pressure During Quiet Breathing and Increased Pulmonary Ventilation A Study in Man J Physiol *127* 423–426 1955

16 Williams Jesse Fiering *The Principles of Physical Education* 3rd Ed Philadelphia W B Saunders Co 1939 p 107

17 Otis Arthur B The Work of Breathing Physiol Rev *34* 449–458 1954

18 McKerrow Colin B and Otis Arthur B Oxygen Cost of Hyperventilation J Appl Physiol, *9* 375–379 1956

19 Jokl Ernst *The Medical Aspects of Boxing* Pretoria J L Van Schaik, Ltd, 1941 p 53

TABLE 15 —Respiratory Muscles and Their Actions

MUSCLES	*INSPIRATION*		*EXPIRATION*	
	Resting	*Forced*	*Resting*	*Forced*
Diaphragm	P M	P M		
The 3 scaleni	Asst *	P M *		Asst (?)***
External and internal intercostals	P M **	P M **		Asst (?)***
Sterno-cleido mastoid		Asst *		
Levatores costarum	Asst (?)	Asst (?)		
Serratus posterior superior	Asst (?)	Asst (?)		
Erector spinae and other oblique spinal extensors		Asst ****		
Pectoralis major and minor and serratus anterior		Asst *****		
Transversus abdominis				P M
External and internal oblique abdominals				P M
Serratus posterior inferior				Asst (?)
Quadratus lumborum				Asst (?)

(?)—Indicates that the action has not been verified electromyographically or is otherwise in dispute

*—When the cervical spine is stabilized by extensor muscles

**—When the upper ribs are stabilized by the scaleni

***—When the lower ribs are stabilized by the abdominals and the quadratus lumborum Electromyographic studies have detected no intercostal activity during expiration

****—Stabilizing the spine in extended position

*****—When the arms and shoulder girdle are stabilized in a position of elevation

Implications for Athletic Training The thoracic cage must function to protect the heart and lungs from the trauma of physical contact The curvilinear design of the ribs, their flexibility, and the network of muscles holding them in position makes these seemingly fragile bones surprisingly resistant to trauma In the young person, however, the flexibility of the ribs may be sufficient to permit the thorax to be distorted to the point that the heart can be injured without fracture of the ribs or sternum Jokl[19] believes that injuries *of this sort are considerably more common in boxing than is generally* realized The possibility of traumata of this type should be carefully considered before permitting young persons to engage in physical contact activities

Young athletes quite frequently complain to their coaches that they have experienced a sharp pain in the region of the heart accompanied by a catch in the breath and are worried about the possibility of having suffered a mild heart attack In the great majority of cases these pains represent nothing more serious than a slight tearing of an intercostal muscle but the coach or trainer should refer such cases to the team physician for consultation rather *than simply reassure the athlete and send him on his way*

Rib strains are quite common in such sports as wrestling in which the hips may be held in one position while the upper body is twisted to another Such injuries are painful during movements of the body but are seldom serious Fractured ribs such as may result from trauma sustained in football skiing boxing and similar activities are quite another matter, since the possibility always exists that the broken rib, or a splinter from it, may penetrate the pleural cavity

Unfortunately there appears to be comparatively little that the athlete *himself can do to prevent such injuries The design of the body* does not lend itself to exercises which will develop muscles which will hold the thoracic cage in place or shield it from injury Prevention of thoracic injuries lies primarily in the design of protective equipment formulation of rules of the game and the teaching of proper techniques and skills

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****—Stabilizing the spine in extended position

*****—When the arms and shoulder girdle are stabilized in a position of elevation

LABORATORY EXERCISES

1 There is evidence that the administration of oxygen to swimmers just before a race improves their times What is the reason for this? Why is it not equally valuable for runners?

2 In lifting a heavy weight overhead a lifter usually takes a full inspiration while the barbell is at the shoulders and then holds his breath as he presses it to arms length What is the rationale for this? What undesirable effects may follow?

3 In his text *The Physiology of Physical Education* (p 518) Percy M Dawson noted that ex wrestlers and weight lifters may be stiff chested with little or no chest expansion How does this condition come about and what is its significance so far as performance is concerned?

4 Assume that a mature individual undertakes a program of weight training and finds that as a result his normal chest circumference is 3 inches larger than it was before he started to exercise How do you account for this change? What would you expect to find true about his chest expansion?

5 What is the effect of pressure on the thorax such as applied in the bear hug in wrestling on respiration? What is the purpose of the wrestler s expiratory grunt?

6 Partially paralyzed patients may be taught a respiratory technique known as frog breathing Determine how this is done and analyze the kinesiological actions involved

7 What may result if an individual practices deep breathing exercises when there is no physiological need for increased respiration?

8 What value should be attached to spirometric tests of lung capacity? What were the reasons for the objections made to the inclusion of this in the Rogers Strength Test?

9 In the Flack Test the subject exhales against a standard resistance of 40 mm of mercury for as long as possible What is revealed by this test? (Suggestion See T J Powell and Sunahara F A A Physiologic Evaluation of the Flack Test J Aviation Med 29 444–453 1958)

10 Analyze the effects of movements of the spinal column such as backward bending forward bending and lateral bending on the respiration Which position appears most advantageous for efficient respiration?

11 Have a subject hold his breath at the end of a normal inspiration Compare chest circumference measurements in slumped normal and exaggerated military posture

Chapter 18

Kinesiology of Posture

EVOLUTION AND DEVELOPMENT OF ERECT POSTURE

Evolution of Erect Posture The upright posture which distinguishes man from all other animals is the product of perhaps 350 000,000 years of evolution In the evolutionary process the paired fins of certain tetrapods whose nearest living relatives are the coelacanths developed into limbs and they moved from the sea onto the land In the course of time—possibly 150 000 000 years ago—the first mammals came into existence By 70 000 000 years ago quadruped primates about the size of rats and probably resembling the modern tree shrews were in existence Over the millennia certain changes in body form adapted them to life as brachiating animals whose weight was *suspended* from their arms The lower limbs were extended in line with the body which assumed a vertical position Brachiation required great mobility in the shoulder girdle and joints lengthened and strengthened upper limbs increased powers of supination and pronation and the development of the prehensile hand The thorax became flattened antero posteriorly, displacing the center of gravity backwards and simplifying the problem of standing erect The scapula moved posteriorly The pectoralis minor insertion shifted from the humerus to the coracoid process The function of the serratus anterior was altered to produce elevation of the arm above the right angle

Some 30 000 000 years ago man s remote ancestors left the trees and became bipedal ground dwellers Further structural changes were necessary for effectively bearing the stresses of body weight which was now *supported* by the lower limbs The leg lengthened and straightened The foot lost most of its grasping abilities and became specialized for bipedalism The large size of the gluteus maximus—an extensor of the hip joint—is peculiar to man It is offset by a corresponding enlargement of the quadriceps femoris which tends to prevent the knee from buckling as a result of the forward momentum of the center of gravity as the foot strikes the ground The plantaris which acts on the toes in most mammals faded to a vestigial muscle while the soleus which acts on the ankle joint alone and is small in most mammals became relatively very large The extensor digitorum longus which is attached to the

femur in most mammals lost this attachment and has no direct action on the knee of man [1, 2] The upper extremities freed from the burden of supporting the body, evolved into instruments of great delicacy of movement

These postural transformations of the body are the culmination of a long series of evolutionary processes and are not something peculiar to man alone as Darwin once thought Not all of these structural modifications have been equally successful The lower extremities have been profoundly modified but the pelvis, by which they are attached to the vertebral column, has remained essentially that of a quadruped Mechanically considered, the spine represents a column Under pressure a column becomes deformed and a curve develops In the vertebral column itself there has been comparatively little adaptation to the demands of upright posture other than the development of a forward cervical convexity a thoracic concavity, and a lumbar convexity Too, the internal mesenteries are arranged for quadrupedal, rather than bipedal position

Posture of the Infant The S shaped spinal curve of the adult develops from the C shaped curve seen in the infant and in anthropoids In the brief interval between creeping and walking the baby recapitulates millions of years of evolutionary change As Keith has observed

> Indeed, it is not too much to say that the spine of the human baby, as regards the proportion of its parts and its curvatures is in an anthropoid or troglodytian phase of evolution We have only to watch an infant trying to support its body erect when learning to walk to see reproduced the orthograde posture of a great anthropoid ape The lower limbs are seen to be imperfectly extended the body plainly inclines forward, and the arms stretch out to clutch at neighboring objects for support In the second year of life growth changes in the lumbar vertebrae make further extension of the body a permanent possibility it is then that the loins elongate and the lumbar curve seen only in the human species, makes its appearance [3]

Effects of Erect Posture When we think of man s form and posture as the result of evolution from lower vertebrate types it is natural to inquire what changes in conditions and functions have come along with it It is apparent that several results are sure to follow whenever a child or a species changes from a quadruped posture to an erect one (1) changes in muscular development (2) changes in coordination (3) changes in the work of breathing (4) changes in the mechanics of the circulation and (5) increased tendency to displacement of the internal organs

Muscular Development Erect posture, with the weight borne by the lower limbs, must result in vastly greater size and strength of the extensor muscles of those limbs and of the lower portions of the trunk greater strength in bones and vertebrae is also a necessity The flexors of the trunk relieved of much of the strain they have to bear in the quadruped position have a tendency to deteriorate

Coordination Greatly increased difficulty in poise and balance in the erect posture leads to a corresponding development of nervous reflexes to maintain exact balance under all conditions while the release of the forelimbs from heavy and monotonous labor leads to their employment in skilled occupations under the guidance of the eyes developing many new coordinations for their control

Breathing In the quadrupedal position the ribs hang down below the spinal column and swing back and forth in breathing like a pendulum, requiring very little muscular expenditure when this mechanism is shifted to the upright position the entire weight of the chest wall must be lifted with each inspiration and must be held up to proper level continuously So great is the pull of gravity on the chest, neck and spine that the ribs gradually sink as age increases and the internal organs sink along with them

Circulation In the horizontal position the blood returning to the heart along the inferior and superior vena cava, the two great veins of the body cavity, flows easily and evenly from the anterior and posterior portions of the body, but when the erect posture is assumed the flow from the head is hastened while that from the lower parts is held back by its weight until there is force enough behind it to overcome gravity This distends the lower vena cava and checks the blood flow to a marked degree

Position of Internal Organs In horizontal position the internal organs while attached to the spine by their mesenteries are supported mainly by the muscles of the body wall, which are kept in constant tension to maintain the arch of the spine There is little or no tendency to displacement of the organs When the erect position is assumed, the weight of each organ tends to pull it downward toward the pelvis lengthwise of the cavity, heavy organs, like the liver and the full stomach, pull strongly on their mesenteries, tending to stretch them and to crowd the organs that lie below To hold these organs up in place calls for a considerable tension of the abdominal wall, but the muscles are no longer kept in contraction to hold up the arch of the spine and therefore tend to relax

CRITERIA FOR GOOD POSTURE

Evaluation of Posture The term "good posture" often conveys the thought of a standing position fulfilling certain esthetic and mechanical specifications Sometimes the postures of school children are graded by such arbitrary standards Whatever the values of a prescribed posture expecting everyone to meet any given standard is to ignore the fact that posture is largely an individual matter Only the muscular type represents the posture generally considered ideal Other types apparently cannot assume this stance and should not be expected to do so [4]

After a study of the posture of college women Wells[5] concluded that their spinal structure could be divided into two classes humanoid with a long posterior concavity extending well up into the thoracic region and anthropoid, with a posterior convexity extending well down into the lumbar region The latter she believes represents inherited types of structures reflecting evolutionary tendencies In her experience these types do not generally respond to corrective exercise

An erect posture is not necessarily the most efficient one The rigid military posture requires about 20 per cent more energy than an easy standing position and an extremely relaxed standing position requires about 10 per cent less energy than an easy standing position [6] Many famous athletes have attributed their success in part to the fact that they were almost completely relaxed between movements thus conserving their energy for purposeful expenditure There is no evidence of physiological benefit from the correction of common

functional postural defects A careful study by Hellebrandt and Franseen[7] has served to emphasize the unsatisfactory scientific basis for many of the current concepts of posture and statements about posture It is plain that upright stance imposes hydrostatic handicaps which increase man s liability to peripheral circulatory collapse, but assumptions that attitudinal anomalies must be positively correlated with functional disturbances are based on very

FIG 158 —Excellent static posture The subject was a winner in a Los Angeles City Schools posture contest (Houston courtesy Los Angeles City Board of Education)

scanty experimental evidence These writers stressed the fact that the body has a remarkable ability to compensate for deviations from the norm and that such compensating mechanisms are seldom considered by those who stress the malign functional effects of poor posture

The esthetic appeal of erect posture and poise balance and ease of motion are not to be denied Physique and beauty contest winners are almost invariably characterized by pleasing posture Strangely enough however the

typical fashion model's stance is apt to be characterized by pronated feet, hyperextended knees, exaggerated lumbar lordosis, protruding abdomen, round shoulders, and a forward head.[7] The difficulties of satisfactorily defining good posture are evident. Wells[8] has rejected all static concepts such as the one holding that the lobe of the ear, tip of the acromion process, middle of the trochanter, and head of the fibula should be aligned vertically, and has suggested that a vertical zone within a centrally located limited area might provide a satisfactory reference plane from which to measure anatomical landmarks.

Conformateurs, comparagraphs, schematographs, silhouetteographs and various other scientific sounding devices have been invented for the graphic measurement of posture. The difficulty with apparatuses of this type is that

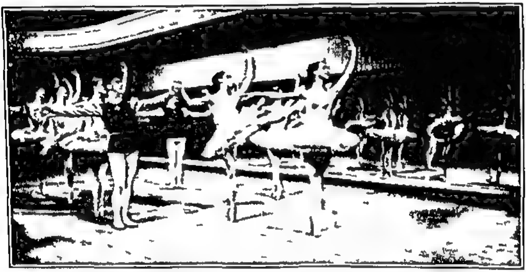

FIG. 159.—Perfect dynamic balance illustrated by dancers of the Ballet Russe de Monte Carlo. Note the extreme range of motion demonstrated in the joints of the lower limbs of the feminine dancers and the precise adjustment of the center of gravity over the very small base. The position of the feet shown in the mirror image of the leading dancer will repay careful study. (Wolff, courtesy Pittsburgh Plate Glass Company.)

while they do provide data about the alignment of the parts of the body, the *significance* of this information rests upon subjective and arbitrary assumptions implicit in the judgment of the measurer.

Esthetic and culturally determined standards cannot be entirely ignored in establishing criteria for posture. The wasp waist of the Gibson girl of the 1890's or the breast minimizing slouch of the flapper of the 1920's cannot be approved kinesiologically, but attempts by the kinesiologist to insist that his pupils adopt postures which are not culturally sanctioned will certainly encounter resistance and may create psychologic trauma no less severe than the physiologic trauma he is trying to prevent.

It is often possible to suggest logical mechanical effects of the assumption of a certain stance. Thus Lowman[9] has called attention to two mechanical consequences of failure to maintain proper balance.

1 Arm and head weight forward of the gravity line must be compensated for by an increase in the dorsal curve of the spine This in turn must be balanced by a forward movement of the pelvis and increased lumbar lordosis The resultant shift of body weight onto the forefoot tends to increase pronation and to depress the arch

2 Concentration on forward arm movements as in the shot put, discus or javelin throw, will eventually result in decreased efficiency because the rhomboids become long and the pectorals shorten As a result the arm cannot be carried back to the maximum shoulder joint range, since the contractile length of the pectorals will not allow it

FIG 160 —Typical fashion model s stance

On the other hand attempts to correct the round shoulders of a basketball player may seriously affect his ability to shoot baskets

Posture must be considered from the standpoint of the individual s body and the use which he makes of that body Perhaps the wisest words yet written on this subject are those of Metheny

> There is no single best posture for all individuals Each person must take the body he has and make the best of it For each person the best posture is that in which the body segments are balanced in the position of least strain and maximum support This is an individual matter *

* Quoted by permission from *Body Dynamics* by Eleanor Metheny Copyright 1952 McGraw Hill Book Co

It has been suggested that the adaptability of a mechanism to make useful adjustments has in large part been determined by the factors of organic evolution but that the agencies employed for this purpose exist primarily for physiological uses and have no special fitness for pathological adaptations [10] The implications of such statements as the foregoing are that the corrective physical educator the corrective therapist, the physical therapist or similar individuals should not attempt to 'correct' an individual s posture unless they clearly understand precisely what steps should be taken and the rationale therefor Ordinarily such information can be obtained only by medical examination and experience indicates that physicians assign only a very small percentage of college students to corrective classes because of postural deviations [11] With younger groups the percentage may be somewhat higher

Maintenance of Posture The righting reflexes by which the animal maintains his posture have been studied in great detail by Magnus [12] They appear to consist of five separate groups of reflexes (1) labyrinthine righting reflexes, (2) body righting reflexes acting on the head, (3) neck righting reflexes, (4) body righting reflexes acting upon the body, (5) optical righting reflexes The centers of these righting reflexes lie in the ventral part of the mid brain behind a section just in front of the third nerves Little is known about the way in which these reflexes cooperate to provide erect posture in the human Presumably stimuli received from any of these sources and from stretch reflexes initiated by proprioceptive mechanisms in the striated muscles reflexly bring appropriate muscles into action to correct displacements from the desired position

Righting Reflexes Although all of these righting reflexes may work simultaneously in some situations not all of the appropriate stimuli may be available in special situations Thus a somersaulting diver or tumbler will not be able to employ (3) or (4) above He must depend upon (1) (2) and (5) If he has not conditioned his visual reflexes or if he closes his eyes during performance (5) is eliminated and only (1) and (2) remain A person who both closes his eyes and because of inexperience or fear cannot utilize the labyrinthine reflexes of (1) and (2) must depend on more haphazard mechanisms Thus some beginners in somersaulting report that they just jump tuck into a ball wait a fraction of a second and then open into the erect position Probably they depend upon an estimation of their speed of rotation together with a guess at the time interval necessary for completion of their somersault but there is always a strong element of luck in this kind of performance Usually experience and confidence will gradually lead to a more finished performance in which a small amount of voluntary control is super imposed upon the workings of uninhibited reflexes

Attitudinal Reflexes Attitudinal reflexes are initiated by movements of the head and result in an adjusted static position The stimuli act upon the receptor organs of the labyrinth the change in posture is brought about by alterations in the tonus of trunk and limb muscles For example tilting the head back in order to look at an object overhead results in shortening of the trunk extensor muscles relaxation of the abdominal muscles adduction of the shoulder girdle a tendency toward extension of the upper limbs and a tendency toward flexion at the knees Conversely lowering the head in order

to peer under an object results in flexion tendencies in the trunk and upper limbs Rotation of the head to one side results in an increase in limb extensor tone on that side and in a decrease in limb extensor tone on the opposite side lateral flexion of the neck (inclination of the head to one side) has a similar effect In sports a side stepping motion is usually initiated by rotating and inclining the head to the side of the step, this reflexly increases extensor tone on that side and instantly prepares the leg on the same side to receive the body weight

The muscles moving the eyeballs are also affected by labyrinthine stimuli resulting from head tilting A forward head movement reflexly tends to move the eyeballs upward a backward head movement tends to move them downward The tendency is always to preserve the original field of vision These reflex tendencies may, of course, be inhibited when they do not serve the purpose of the organism In the example of deliberately looking at an object overhead the reflex tendency to lower the eyeballs, as the head is tilted back, is superceded by voluntary raising of the eyeballs

Positive Supporting Reflexes In all of the positive supporting reflexes the result is to increase extensor tone or flexor and extensor tone in order to make the body rigid against the force of gravitational pulls The following are examples (1) The stretching of toe flexors, foot flexors and ankle plantar flexors as a result of pressure on the ground causes reflex contraction of the extensors (or flexors and extensors) of the knee (2) Any tendency toward overextension (stretching) of distal limb muscles causes a myotatic contraction of these muscles and their synergists tending to correct the balance of the body and counteract gravitational forces (3) Stepping on a surface stimulates the pressure receptors in the soles of the feet causing a reflex contraction of limb extensors This is known as the *extensor thrust* reflex its utility in locomotion and standing is obvious

The positive supporting reflexes are usually considered to be static reflexes—that is useful in the maintenance of stationary erect posture During locomotion however these same reflexes assume equal importance For example in the last phase of weight bearing by a limb (the push off phase) the toe and foot plantar flexors are stretched resulting in a myotatic contraction of these same muscles thus reflexly giving additional force to the push off

Negative Supporting Reflexes The characteristic of negative supporting reflexes is a limb flexion followed by a placing and extension of the limb for support purposes It is best demonstrated in blindfolded animal or human subjects (animals may also be labyrinthectomized) For example a cat in such a state may be held by the body in mid air Then if a board is touched lightly to the top of one of its paws that paw is reflexly withdrawn slightly replaced on top of the board and extended Or, if the standing animal is pushed sharply to one side there is a hopping reflex which involves sudden pushoff flexion withdrawal and replacement of the paw under the new location of the center of gravity of the animal The object of these and numerous allied reflexes is replacement of the foot (or hand) in a supporting position with terminal contraction of the extensor muscles

Developing Reflex Actions All such reflexes as the foregoing and many more are learned or conditioned reflexes probably Very few are present in the newborn child and maturation of the nervous system is inadequate to

provide a complete explanation of their development In many humans there is a tendency to depend most strongly upon visual reflexes for balance and dynamic movement In sports and emergency situations, such strong dependency upon visual reactions and the consequent lack of development of the non visual mechanisms may be a distinct disadvantage, because the vision may be temporarily impaired or obscured by numerous situational factors and the visual field may not be sufficiently broad or steady to perceive all of the available visual cues Normal people, like those who become permanently blinded can develop labyrinthine proprioceptive and other mechanisms far beyond so called normal levels Sports like tennis and base ball which emphasize visual perception may not be as suitable as aquatics tumbling and balancing for the sharpening of a broad repertoire of labyrinthine and proprioceptive reflexes although these mechanisms once developed, can be used in such sports Conversely, hand eye and other eye to muscle reflexes may be most easily trained in ball sports A child s experience in motor activity should involve a great variety of activities Specialization at too early an age may limit the ultimate extent of ability in that specialty At the higher levels of performance in a given specialty the better performers are likely to be those whose perceptual and motor learnings are most versatile Some basketball players for instance can effectively initiate pivot style shots while their backs are toward the basket They rely upon a visual memory the location of the basket with regard to themselves upon initial movements guided by proprioceptive reflexes and only at the last moment upon visual perceptions to make final adjustments to the motor act of shooting for the basket

It has been calculated that the force which must be exerted by the calf muscles to maintain the upright position is equal to about one quarter of the body weight In subjects standing at ease, electrical potentials were recorded from the soleus muscles of all subjects and from the gastrocnemius muscles of the majority of the group Potentials were occasionally obtained from the tibialis anterior and peroneus longus Most subjects were found to stand at ease without detectable activity in the quadriceps and hamstrings This was explained on the basis that since in this position the line of body weight usually falls in front of the center of the knee joints the weight of the body above the knees is supported by the ligaments of the knee joint Shifting of the line of body weight posteriorly or anteriorly to this point results in contractions of the quadriceps or hamstrings to preserve the stance In the erect posture there is continuous contraction of the internal oblique fibers possibly to protect the inguinal region from hernia As the subject sways back and forth the rectus abdominis and sacrospinalis contract alternately to correct the resulting displacement [13 18]

The basic response of individual muscle fibers to a stimulation is probably a twitch rather than tetanus The immediate result is the production of essentially oscillatory forces Tremor at the rate of about 10 cycles per second appears to accompany muscular contraction in mammals With an increased load on the musculature a progressive increase in the amplitude of this tremor becomes evident [19] The approximate metabolic cost of various types of posture is shown in Table 15 [20] These figures may be altered by the individual s body weight degree of sway and other factors

TABLE 15 —Metabolic Cost of Various Types of Posture

	Calories per minute	*Per cent greater than lying*
Lying	1 14	—
Sitting	1 19	4 4
Standing relaxed	1 26	10 5
Standing at attention	1 30	14 0

The Structure of Erect Posture *The Feet* The rigid structure comprising the human foot has evolved from the flexible grasping organ of the arboreal pre human The functional grasping muscles are still present in the human foot, but are reduced in size and subordinated to the structural demands required in providing propulsive leverage Most babies are flat footed when they begin to walk The short plantar muscles gradually tighten up, the anterior and posterior tibials raise the inner border of the foot and the longitudinal arch forms [21] No one type of arch can be considered normal, and the height of the longitudinal arch has no relationship to its reaction to the stress of weight bearing The predominant opinion is that there is no such thing as a transverse arch at the distal ends of the metatarsals [22 23]

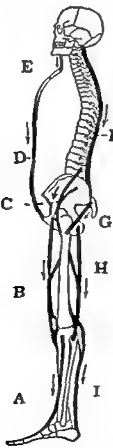

FIG 161 —Antagonistic muscle groups responsible for erect posture A Tibialis anterior B Quadriceps femoris C Ilio psoas D Abdominals E Neck flexors F, Spinal extensors, G, Gluteus maximus H, Hamstrings I Triceps surae

The natural position of the feet is one in which the heels are together and the fore parts of the feet are toed out sufficiently—30 to 40 degrees—to give stability to the lateral balance of the foot The line of the body's center of gravity is perpendicular to a point midway between the heels and the heads of the first metatarsal bones In standing the weight should be about equally distributed between the ball of the foot and the heel [23] Under the stress of weight bearing the foot both lengthens and broadens slightly There is a reflex postural contraction of the abductors hallucis, the minimi digiti, and the adductor hallucis and the other plantar muscles in response to proprioceptive reflexes [24] but the greater portion of the tension stress is borne by the plantar ligaments [22] Structural or functional foot abnormalities must be corrected or compensated before good posture can be achieved

The Legs and Knees The proper position of the legs, with regard to inward or outward rotation at the hip joints is best explained by imagining that the patellae are eyes, and specifying that they should be looking in exactly the direction of a line drawn longitudinally from the heel through the center of the foot If in any weight bearing activity the feet are 'toed out' or toed in,' there should be an accompanying outward or inward rotation of the thigh at the hip joint Otherwise, there will be undesirable strain at the knee and ankle joints This principle assumes more importance during body movement and is often stressed by dance teachers whose medium often requires foot position or progression in a diagonal direction The military position of attention with feet at a 45 degree angle, is disadvantageous to the entire lower extremity and especially to the foot It tends to pronate the foot and to stress the supporting structures of the arch

The energy expenditure of stationary standing is less if the knee and hip joints are slightly hyperextended since ligaments then bear the weight and allow extensor muscles to relax However, this results in a pooling of venous blood in the lower extremities So does standing with the knees slightly flexed which has the additional disadvantage of hastening fatigue If continued stationary standing cannot be avoided (as during a military review) venous stagnation can be allayed and fainting prevented by deliberate intermittent contraction of leg muscles

The Pelvis The importance of the function of the pelvis in maintaining the ideal erect posture and its role in good body mechanics cannot be overemphasized It is one of the most important structural units of the body It supports the body weight from above and conveys it to the legs Because it joins the immovable portion of the spine to the flexible mobile portion deviations from its normal position are reflected the full length of the spinal column The pelvis also acts as a sort of shallow cup which supports and partly contains the pelvic viscera

Normally the anterior superior iliac spines and the front of the pubic crest lie in the same frontal plane Any pronounced deviation from this position materially hinders the functioning of the pelvic viscera An upward tilt of the pubis straightens the lumbar section while a downward position causes a lumbar curve which if prominent is a hollow back When the downward tilt is exaggerated the pelvic contents are thrown forward and tend to spill over the anterior lip of the pelvic cup the pubic arch This throws an additional strain on the abdominal muscles (Fig 162)

In addition to the pelvis being tilted from its optimum position in the anterior posterior plane it sometimes happens that one side of the pelvis is higher than the other This may be caused by inequality in the length of the legs a flat foot, or by muscular atrophy of one of the legs The fixed portion of the spine is tilted to one side The mobile portion of the spine therefore rests on an inclined surface, resulting in further deviations from the ideal erect posture

An exaggerated pelvic tilt causes the buttocks to protrude, and gives rise to an awkward gait

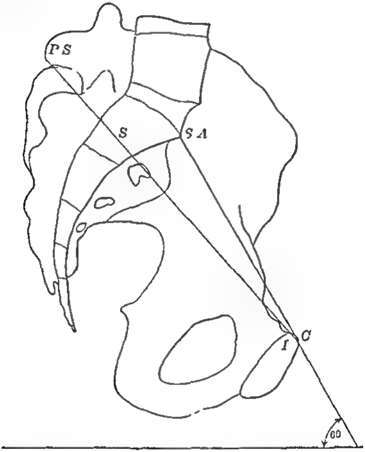

FIG 162 —Median section through the pelvis *P* pubes *C* pubic crest *S*, sacrum *S A* sacral angle *P S* posterior spine (Spalteholz)

Attempts have been made to measure the pelvic angle on a living subject and earlier workers estimated the ideal or normal position as having an obliquity of 50 to 60 degrees Later workers have agreed that it is impossible to measure accurately the pelvic tilt on a living subject Hyperextension of the knee tilts the pelvis forward while flexion tips it backward

The oblique position of the pelvis brings the pelvic organs far to the rear, where they are beneath the sacrum and protected somewhat by it from the weight of the organs above it also brings the lower lumbar vertebrae far enough forward to be practically over the hip joints so that little force is required to maintain poise

The Vertebral Column Viewed laterally, the vertebral column exhibits three curves a forward cervical convexity a thoracic concavity, and a lumbar convexity The lumbar region is not well buttressed by muscle, and the rectus abdominis is the only longitudinal anterior muscle directly controlling the amount of lumbar curvature A common analogy is that it acts like a bow string the lumbar curve being the bow Some assistance is afforded by the compression of the abdominal contents by the oblique abdominals, these compressional pressures being transmitted as forces tending to straighten out the lumbar curve

The Abdominal Wall The four pairs of muscles in the abdominal wall—recti, internal and external obliques and transversales—are involved in two important reflexes those of posture and breathing A third function of this group of muscles is to maintain suitable support for the internal organs

The Shoulder Girdle and Chest The best functioning of the internal organs calls for an erect position of the chest and neck and a moderate adduction of the shoulder girdle The tidal movements of the ribs should take place in a range midway between full inspiration and full expiration This semi elevated position of the ribs and sternum takes up the slack in the abdominal muscles and provides a good base for their action

The Head The head should be kept in a well balanced position When it is allowed to droop forward habitually undue strain is placed on the ligaments and extensor muscles of the neck and back People who frequently carry moderately heavy loads on their heads develop an excellent position for the head neck and back If they did not keep the body head and load in perfect balance they would either drop the load or be subjected to so great a strain that they could not maintain their erect position

Implications for Good Posture What are the postural implications to be derived from knowledge of man s evolutionary past and from biological mechanical and physiological data? The evidence does not lead to clear cut answers but the following generalizations might be suggested *First* static erect postures should be deliberately avoided except for short periods *Second* in sitting or recumbent positions properly placed environmental supports (such as firm mattresses or chair backs) should be available to re place the function of muscle groups which are relaxing *Third* in stationary postures the center of gravity of each body segment should be vertically above the area of the supporting base, preferably near its center If persistent gravitational torques are being borne by ligaments or if excessive muscular contraction is required to maintain balance this principle is being violated Thus it is permissible to bear weight on the knee or hip ligaments by slight hyperextension of these joints, but excessive weight bearing by the spinal ligaments over a period of time will prove damaging *Fourth*, rhythmic reciprocating movements (such as walking) are beneficial, because they facilitate return of venous blood toward the heart and because the intermittent relaxations tend to postpone fatigue *Fifth* the bones tendons and muscles should be strengthened and toughened through gradual progressive stresses and resistances, so that they may cope adequately with the common forces encountered in daily living (Do ligaments also respond favorably to gradual progressive use? Research evidence is lacking) *Sixth* in forceful dynamic movements (such as sprint starting or a football lineman s charge) the forces

In addition to the pelvis being tilted from its optimum position in the anterior posterior plane it sometimes happens that one side of the pelvis is higher than the other This may be caused by inequality in the length of the legs a flat foot or by muscular atrophy of one of the legs The fixed portion of the spine is tilted to one side The mobile portion of the spine therefore rests on an inclined surface resulting in further deviations from the ideal erect posture

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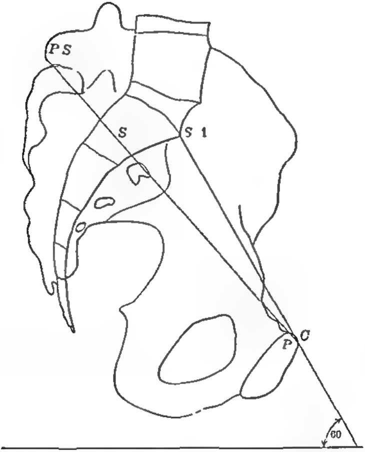

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Wrong habits of posture are caused by injury and disease and by occupation and environment as well A boy who sprains his left ankle has to stand on his right foot and during the period of lameness he forms the habit of standing on that foot and is likely to keep on doing so for years A boy who has carried a heavy sack of papers on one shoulder every day for a year or two is apt to hold that shoulder low for the rest of his life

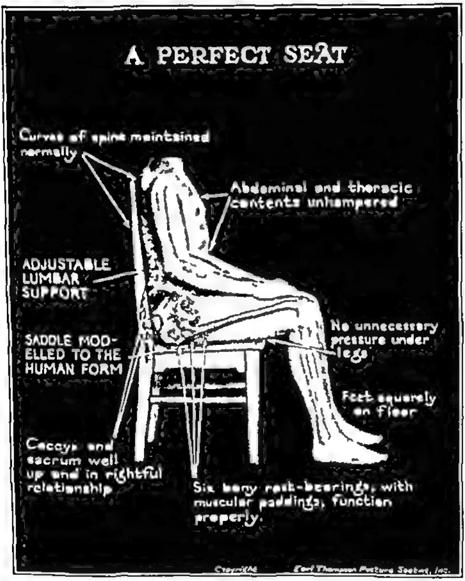


FIG 163 —The good points of a perfect seat (By permission of Earl Thompson Posture Seating Inc)

Thus bookkeepers are known by their peculiar habit of holding the head and cowboys by their bowlegged gait Seats shoes and clothing produce similar effects when they have the wrong size or shape so that they hold one in a faulty position defects of vision and hearing and resting positions on rocking chair lounge hammock or bed may induce such habits also

On the other hand, those who are strongly impressed with the advantages

should be directed as much as possible in a straight line which intersects the major joints metatarso phalangeal knee, hip, and shoulder At the same time spinal curves should be minimized, so that they will be ready to bend in a spring like fashion as they absorb impact forces Impact forces may injure locked joints, but joints which are able to move in either direction are mechanically ready to absorb them (Goldthwait s factor of safety[25]) *Seventh* the guiding principle in maintaining postures and in moving should be *efficient energy expenditure* This concept of optimal (not minimal) energy expenditure has been extensively developed by Metheny [26]

CAUSES AND CORRECTION OF POOR POSTURE

Causes of Poor Posture Defects of posture may result from (1) injury (2) disease (3) habit, (4) muscular or nervous weakness (5) mental attitude (6) heredity, or (7) improper clothing

Injury When a bone, ligament or muscle is injured it is apt to weaken the support at that point and throw the framework out of balance As long as this condition is present, perfect posture is impossible after the injury has been fully repaired a habit set up may persist and the faulty posture continue for a long time Since minor injuries, like a sprained ankle often occur and since there is seldom any effort made to re educate the reflexes of the wrong habit we frequently see defects of posture that arose in this way

Disease Diseases that weaken bones or muscles or cause joints to lose their strength or their freedom of action upset the control of posture as badly as injuries Rickets, due to faulty nutrition of bone and tubercular disease of joints or vertebrae are examples of this kind Infantile paralysis by weakening or destroying the motor nerve cells in the spinal cord causes partial or complete loss of function in certain muscle groups This loss of power in the muscles upsets the control as in the former instances and also causes another kind of defect the uninjured group that is the natural antagonist of the paralyzed one, not having its normal opposition, becomes gradually shortened and holds the joint out of normal position For example one with a paralyzed gastrocnemius gradually develops a flexed ankle which he cannot extend

The treatment of cases involving severe injury or disease often requires surgical measures such as cutting a muscle or tendon removing or grafting bone transplanting of tendons to make good muscles do the work of absent ones and the making of braces to support the weight when the natural support is lacking

Habit Habits of posture whether good or bad are acquired in the same way as habits of speech or habits of walking namely, by practicing a certain coordination so many times that the act finally becomes habitual and unconscious and is performed whenever the appropriate situation presents itself In a very large percentage of the cases of faulty posture found among school children and college students the bones joints ligaments and muscles are in normal condition the fault is a wrong habit of coordination Segments of the body have been held out of line so long with some parts bearing too much weight and others too little some muscles elongated and their antagonists shortened, that the wrong posture feels natural and a correct position seems strange

This appears to result from the fact that with high heels the center of gravity is shifted forward and the dorsal muscles must contract in order to prevent the body from falling forward [15, 16]

Removing the Causes Whenever faulty posture is due to disease the disease must be treated before anything else is attempted if it is due to an injury, the injury must be healed In general the cause must be removed before any measures for improvement are apt to be effective a posture due to wearing high heels will not be much improved as long as the high heels are worn, an hour in the gymnasium will not cure bad postures when many hours are spent in the environment that caused them Some cases of faulty posture are due to fatigue mental strain improper digestion and assimilation of food malnutrition, or similar causes Here rest and proper nutrition are fully as important as a program of corrective activities

Special Posture Classes Many pupils are not strong enough and skillful enough to assume and maintain correct posture These require more personal attention than can be given the average pupil Special classes of small size should be conducted for them More complete study of each case and of its causes is then possible

When poor posture is due to general muscular weakness, such students can be placed in the same class and given developmental exercises and games to suit their individual needs Due regard must be taken for the cause of each individual s shortcomings and corrective procedures in line with the best educational and orthopedic practice instituted This demands individual attention The placing of *all* students with postural defects in a single class and giving them the same treatment is as unwise as it would be for a physician to prescribe the same therapy for all patients exhibiting a skin rash

Referral Cases Posture defects which cannot be voluntarily corrected by the subject s own volitional movements are known as *resistant or structural defects* All such cases should be referred to a physician preferably an orthopedist Expert diagnosis including x rays and other medical techniques, is necessary before any treatment is given Not all such cases yield to exercise therapy, but the physician may make an exercise prescription and direct the patient to a physical corrective or occupational therapist or to a physical educator for supervised exercise Coaches and physical education teachers make a valuable professional contribution when they recognize the possibility of severe problems and make referrals to a physician but they act unethically and perhaps illegally when they treat cases without the permission or prescription of a licensed doctor

SPECIFIC DEFECTS AND THEIR CORRECTION

Foot Defects The nature of the arches and the structures supporting them has been explained in pages 282 to 285 The term *flat feet* or fallen arches may refer to several different defects *Flexible flat foot* exhibits loss of the arches only during weight bearing and is not regarded as pathological unless accompanied by discomfort or interference with function True flat foot or *pes planus* is a structural anomaly sometimes hereditary or congenital which may or may not be accompanied by discomfort and interference with function *False flat foot* is not a defect but a condition resulting from the presence of

of good posture, so that they study their own postures and try to improve them, just as thoroughly as they study to improve their complexions and the appearance of their clothes are apt to have correct habits of posture in spite of occupation and environment

Weakness The erect posture cannot be maintained without the expenditure of energy and therefore requires some strength and endurance Posture is a sensitive indicator showing to one who can read it not only our habits but also the level of our store of energy It has been demonstrated that a slouched position can be maintained at less metabolic cost than the erect alert position, largely because the subject is supported by the ligaments of hyperextended joints which provide the necessary support rather than by the action of muscles Muscular weakness and the lack of vitality then necessarily predispose one to assume such a slouched posture as a matter of energy conservation Because general muscular weakness is one of the common causes of poor posture, an active childhood involving vigorous exercise obtained by engaging in games and sports is perhaps the best preventive measure that can be undertaken The type of activity or game selected is important Interest of the pupil in the game should be one of the most potent guiding factors because strong interest results in continued participation The correction of general muscular weakness may take a long time therefore sustained interest is necessary The activities should be sufficiently vigorous to provide for organic strength *If possible the activities should also provide for a balanced bilateral* development

Mental Attitude Posture frequently reflects the mental attitude Feelings of elation confidence and satisfaction help in the maintenance of erect posture humility and depression hinder it A good mental attitude is likewise reflected in an erect alert posture a poor mental attitude is reflected in poor posture

Heredity McCloy[27] has shown that kyphosis may be hereditary, and it is possible that other postural defects may have a genetic basis

Improper Clothing High heels are the special target of many orthopedists Stewart[28] considers them the most destructive factor in foot physiology, and terms them essentially a prosthesis for a deformity He considers that high heels

1 Cause a decrease in the tone of the postural muscles and an increase in the tension on the plantar fascia

2 Shorten the leverage of the foot for propulsion and increase the muscular effort required in the pushoff

3 Decrease the postural power of the erectors of the tibia A structural shortening of the tendon of Achilles occurs and relaxation of the hamstrings upsets the whole postural mechanism

4 Keep the toes in partial or complete dorsiflexion The more they are dorsiflexed the greater the weight thrown on the articular surfaces of the metatarsal heads As the toes are dorsiflexed they tend to spread apart but high heels are usually accompanied by pointed toes which increases the strain

Electromyographic studies have shown that when high heels are worn a marked increase of activity in the gastrocnemius soleus and peroneus longus muscles results whereas the tibialis anterior is not affected to any great extent

individual susceptible to them, and may even be a primary causative factor in a sedentary person Basmajian and Bentzon[16] report that

> It now seems to be beyond controversy that tibialis anterior, peroneus longus and the intrinsic muscles of the foot play no important active role in the normal static support of the long arches of the foot However, no attempt is made to suggest that the muscles play no role in the abnormal flat foot Furthermore we are not dismissing the role of these muscles in the maintenance of the arch during locomotion Indeed the intrinsic muscles of the foot are always very active electromyographically when one rises on the toes to even the slightest degree

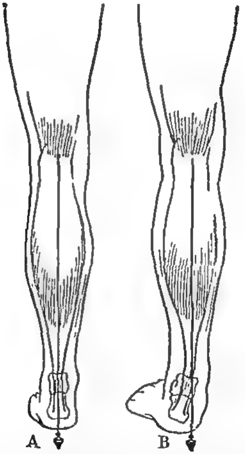


FIG 165 —The position of a plumb line dropped from the middle of the popliteal space in the normal A and the pronated B (Lewin courtesy Am J Dis Child)

Exercise for the correction of habitual and functional defects should be general and involve the foot as a whole Stronger individuals may benefit from rising on the toes with the weight shifted toward the lateral borders of the feet but usually non weight bearing exercises are preferred The foot should be put through the extreme range of all of its motions by voluntary contraction to stretch the shortened soft structures The emphasis should be upon exercises involving toe flexion foot and ankle plantar flexion and supination

a pad of fat on the plantar surface, under the arch None of the foregoing are likely to be affected beneficially by exercise There remains the very common *functional flat foot* caused by weakened and stretched muscles ligaments, and plantar fascia This type ordinarily responds to exercise, and should be corrected even when no discomfort results because it may distort the mechanical relationships in other joints, causing symptoms to appear at the ankle, knee, hip, and lumbar spine

Such defects as *pes cavus* (a rigid and greatly accentuated longitudinal arch)

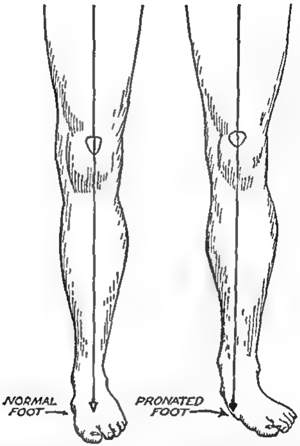


FIG 164 —Showing the position of a plumb line dropped from the middle of the patella in the normal and flat foot (Lewin courtesy Am J Dis Child)

pes equinus (permanent plantar flexion and raised heel) and the various club foot conditions require surgical treatment

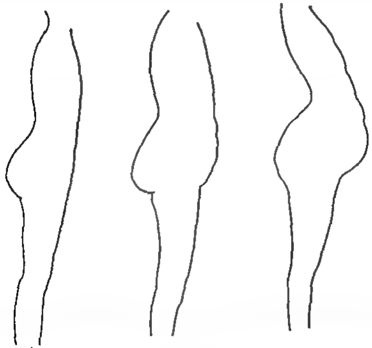
Habitual pronation of the foot is a common defect which usually responds to exercise therapy and habit training provided that the existence of structural and orthopedic lesions have been ruled out The symptoms include a curved or slanted tendon of Achilles protruding internal malleolus toeing out and a pseudo flat foot caused by the rolling inward of the ankle Flat foot may or may not be an accompaniment (Figs 164 and 165)

Stationary standing although it demands much energy expenditure does not provide good correction for any of the foot defects Instead it renders the

inward rotation occurring at the hip and foot joints The appearance of the defect is indicated by its nickname of "cross eyed knees" It is often a functional result of habitual flat feet and pronated ankles and (if severe structural conditions are ruled out by an orthopedist) exercise treatment may be undertaken with emphasis on correcting the basic foot defects (Fig 166)

Abdominal Wall Defects The abdominal defects discussed here are intimately related to the spine defects considered in the following section, and vice versa The division is made for convenience only

The stomach liver, small intestine colon and other organs completely fill the abdominal cavity and each is attached to the posterior body wall As long as the trunk is horizontal the organs lie normally in place, even when the abdominal wall is fully relaxed, but as soon as the erect position is assumed



A B C

FIG 167 —Tracings showing sagging abdomen with indication of ptosis *A* normal outline *B* and *C* weak abdominal walls with apparent sagging of the viscera

their weight pulls them downward lengthwise of the cavity the mesenteries by which they are attached are not composed of strong fibrous tissue like true ligaments but are mere folds of the soft peritoneum in which the arteries veins and nerves going to the organs are enfolded When the right amount of pressure is maintained by a coordinated action of the four pairs of abdominal muscles the organs are held in proper position in upright postures even when subjected to the jar of running and horseback riding

Visceral ptosis is the medical term for the sagging of the organs and their downward drag upon their mesenteries that takes place when there is not sufficient tension of the abdominal wall to hold them up in place The pull on vessels and nerves causes nervous irritation whose cause is not easy to find if continued for a long time the organ sags to a lower place in the cavity,

Functional defects of the foot can be caused or intensified by a shortened tendon of Achilles, and this is very common among women and young girls who wear high heeled shoes constantly To stretch the tendon and its muscles assume the long sitting position (with knees extended in order to take up the slack in the gastrocnemius) and use muscular contraction to move the foot forcibly into a position of dorsiflexion and supination An often recommended but questionable exercise is standing with the balls of the feet on the edge of a platform with heels protruding over the edge Any bouncing on the tendon of Achilles would tend to initiate a stretch reflex in the soleus and gastrocnemius muscles and would tend to break down the longitudinal arch by reason of the rotational torque exerted on the calcaneus Further, this exercise has no

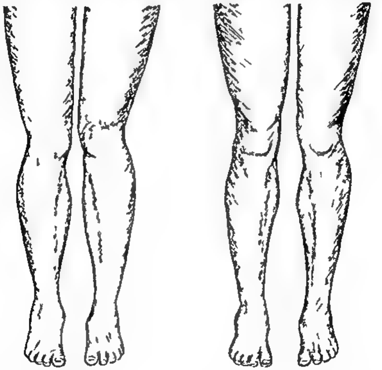


FIG 166—*A* Tibial torsion *B* Correction of tibial torsion resulting from contraction of the outward rotators of the femur (After Hawley)

tendency to strengthen the supinators and plantar intrinsic muscles which are usually weak and stretched in individuals having a shortened heel cord

Leg and Knee Defects *Genu valgum* (knock knees), *genu varum* (bow legs) *genu recurvatum* (hyperextended knee) and *tibial torsion* (twisting of the tibia on its long axis so that it proximal end appears to be inward or outward rotated) are complicated deformities which require orthopedic attention Exercise correction should not be undertaken without the permission or prescription of a physician The defects may appear to be in the knee joint but usually the entire length of the femur and tibia is involved with abnormalities of growth occurring at the epiphyseal plates if the bones are immature

The term *tibial torsion* is also frequently used to designate a functional

inward rotation occurring at the hip and foot joints The appearance of the defect is indicated by its nickname of "cross eyed knees" It is often a functional result of habitual flat feet and pronated ankles and (if severe structural conditions are ruled out by an orthopedist) exercise treatment may be undertaken with emphasis on correcting the basic foot defects (Fig 166)

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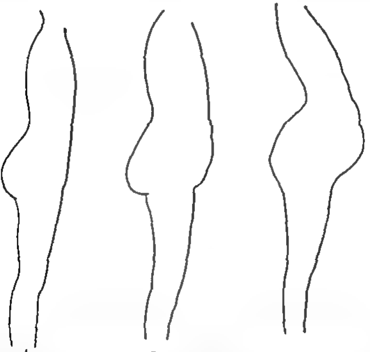

A *B* *C*

Fig 167 —Tracings showing sagging abdomen with indication of ptosis *A* normal outline *B* and *C* weak abdominal walls with apparent sagging of the viscera

their weight pulls them downward lengthwise of the cavity the mesenteries by which they are attached are not composed of strong fibrous tissue like true ligaments but are mere folds of the soft peritoneum in which the arteries veins and nerves going to the organs are enfolded When the right amount of pressure is maintained by a coordinated action of the four pairs of abdominal muscles the organs are held in proper position in upright postures even when subjected to the jar of running and horseback riding

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stretching the connecting vessels and crowding the organs below A sagging abdominal wall may permit displacement of the internal organs and contribute to their malfunction (Fig 167)

The lack of suitable muscular tension in the abdominal wall has another effect it leads to dilation of blood vessels in the digestive organs, favoring inflammatory conditions The presence of fat adds to the weight and hence to the tendency to sag and to the distention of the wall

Hernia or rupture is a protrusion of some abdominal structure through an opening in the abdominal wall The weakest point in the abdominal wall in the male is usually the inguinal canal just above the groin and near the crest of the pubes, in the female it is usually the femoral canal where the femoral artery crosses the rim of the pelvis, this is slightly lateral to the inguinal canal The immediate cause of a hernia is usually some sudden and violent contraction of the abdominal muscles due to a fall or other accident or to a violent fit of coughing forcing a portion of the intestine through the weakened spot Sometimes no definite immediate cause can be assigned The real cause is a weakness of the abdominal wall

When a hernia has occurred once it is liable to occur again, since the protrusion stretches the ring of tissue and makes the opening larger The cure is accomplished by a simple operation

Prevention of visceral ptosis and hernia is by maintaining the strength and thickness of the abdominal wall Sedentary life predisposes to these troubles by lack of bodily activity that is the natural means of its development It also encourages a deposit of fat in the mesenteries the weight of which tends to increase the sagging Quiet breathing scarcely employs the abdominal muscles at all sitting, either when bending forward or leaning against a support, makes it unnecessary to use them in maintaining the posture Walking, running, and active games and sports bring them into action in the natural way and so these activities are the best means of development and the best preventive measures Special exercises in bending twisting raising and lowering the trunk and moving the lower limbs can help if carefully used but they are apt to be used too violently and for too short a time

Round Shoulders This fault in its early stages consists merely of a forward drooping of the head and neck, with a consequent abduction of the scapulae due to stretching of the middle trapezius and the rhomboids The unbalanced position of the head pulls forward on the extensors of the upper spine stretching them and causing fatigue The head and neck are thrust forward and the chest is flattened, because the lowering of the origins of the sternocleidomastoid and the scaleni muscles permits the ribs to fall In the later stages an increased convexity of the normal thoracic curve of the spine a postural fault known as kyphosis is produced In this position the weight of the arms and shoulders accentuates the kyphosis and shoulder girdle abduction

Causes and Frequency Round shoulders is the most common fault of posture Nearly all school occupations including reading writing drawing solving problems in mathematics library work and laboratory work keep the head bent forward so that the eyes can be used to direct the work of the hands or to read the printed page Fortunately there are other school occupations such as working at the blackboard reading from charts looking at illustrative

apparatus or at one who is speaking in which the head is held erect Many home occupations are also conducive to round shoulders sewing sweeping, ironing and playing cards for examples Any occupation in which the individual routinely works with the arms in front of the body tends to develop residual tension in the pectorals pull the clavicle forward abduct the scapula, and produce round shoulders

Among students, reading is the occupation in which most hours are spent It is for this reason the most important single cause of round shoulders Holding the book up before the eyes tires the arm muscles, the book is allowed to drop to the table or the lap, and the head droops to bring the eyes within range

Corrective Exercises Exercises devised for the prevention and correction of round shoulders are illustrated in Figures 75 and 76 Persistent practice of these exercises will help to elongate the shortened muscles and to correct the faulty reflex that has allowed the back muscles to keep habitually in too great a degree of elongation For those who need more vigorous exercises the same ones can be practiced while lying prone with the feet held down

As in all correction of posture, it is of course not enough to stretch the short tissues and make it possible to assume an erect posture, the habit of correct posture must be fixed by the subject himself, through education of his nervous reflexes by persistent practice

Kyphosis Analytically kyphosis and round shoulders are distinctly different, the former being an increased convexity of the thoracic spine and the latter being a forward deviation of the shoulder girdle However, one begets the other and the two commonly appear together as an integrated defect

Resistant or structural kyphosis or any such defect accompanied by acute pain indicates probable disease or hereditary defect of a more serious nature Except on prescription of a physician, corrective exercises should never be given in such cases

Hollow Back There are two types of hollow back which in resistant stages is called *lordosis* The simpler is merely an exaggeration of the normal lumbar curve in the more complex type the pelvis is tilted forward

The simpler type of hollow back is illustrated in Figure 168 It is assumed temporarily whenever one carries a weight in the arms held in front of him as when a waiter carries a heavy tray of dishes The muscles of the lower back are shortened and the abdominal muscles are elongated When this position is assumed habitually too much weight is thrown on the posterior edges of the bodies of the lumbar vertebrae and there is a marked tendency to assume a position of round shoulders to compensate for the backward shifting of the body weight In flexible cases the subject has only to acquire the ability to assume the right position of the spine and then to practice it until the habit is established In cases that are slightly resistant there are two kinds of exercises that will help to elongate the back muscles and to shorten the abdominal group

Sitting on a bench against a wall and pushing the trunk backward so as to make it touch the wall in the lumbar region is good it is a little stronger if taken while sitting on the floor with the knees straight as this tilts the pelvis backward and so helps to straighten the lumbar spine

An exercise suitable for vigorous subjects is taken while lying on the back

stretching the connecting vessels and crowding the organs below A sagging abdominal wall may permit displacement of the internal organs and contribute to their malfunction (Fig 167)

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some careful work with the help of the instructor a few will learn to control the tilt of the pelvis at will, and then the right habit can be established with comparative ease Others can learn to keep the front of the pelvis up by rising carefully and slowly from the sitting position, contracting the abdominal muscles first and then the hamstrings, with as little tension as possible on the back muscles and the flexors of the hips If the iliofemoral ligaments are short, they will tilt the pelvis forward in spite of all the muscles can do to prevent it

When the flexors of the hips and iliofemoral ligaments are just a little short it may be possible to stretch them in the following manner lying flat on the back on the floor knees extended, try to press the lumbar part of the back close to the floor possibly putting one hand there and trying to press the back against it will help in the coordination The work has to be done by the hamstrings and abdominal muscles, against the resistance of

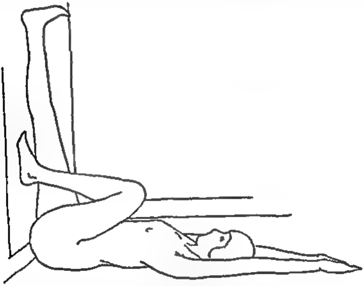


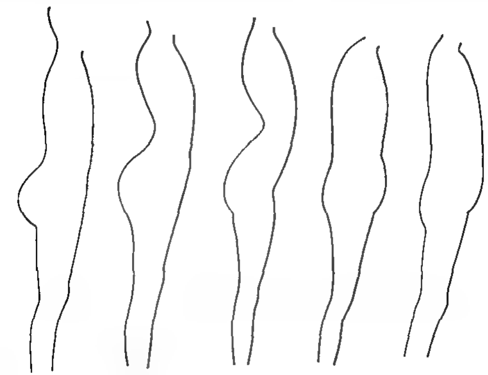
FIG 169 —The bicycle exercise (Drew)

the back muscles flexors of the hips and iliofemoral ligaments A variation that will sometimes help is this flex the knees a few degrees sliding the feet along the floor toward the hips then press the back down against the floor now while holding the back down slowly extend the knees This uses the extensors of the knees along with the hamstrings and abdominal muscles to stretch the flexors of the hips and the iliofemoral ligaments

Flat Back Flat back is the absence of the normal lumbar curve It is a reversion to the posture of the apes whereas hollow back is too great a departure from it Here the pelvis is held too flat the hamstrings being short and the flexors of the hips and iliofemoral ligaments too long it may be developed by a habit of sitting with the hips forward and the lumbar curve obliterated As in the former case when the condition is flexible a better coordination can be acquired and a new habit of holding it established the right position may be acquired by rising slowly from the sitting position with the trunk held well forward fixing the position of the pelvis by contraction of

on the floor with the hips flexed until the feet are vertically over the face and 12 to 18 inches away from it the hands or a pillow may be used to hold the hips off the floor From this position move the feet in a circle as large as can be made conveniently The back muscles are kept in a stretched position and the abdominal muscles used moderately in a shortened position The so called bicycle exercise is easier here the hips are against the wall and the lower limbs extended upward along the wall, from this position one limb is flexed and extended in alternation with the other, as in bicycling (Fig 169)

When the pelvis is tilted too far forward we have not only a wrong coordination of the flexors and extensors of the trunk but also a wrong coordination of the flexors and extensors of the hips at the same time In this case



A *B* *C* *D* *E*

FIG 168 —Tracings made with pantograph showing normal posture lordosis and flat back *A* normal *B* and *C* lordosis *D* and *E* flat back

the back muscles and flexors of the hips are shortened, while the abdominal muscles and hamstrings are elongated It will do no good to correct the coordination of trunk muscles alone or of hip muscles alone all four groups must be adjusted and controlled to keep the pelvis in its proper degree of inclination

It will be readily seen that the exercises that have been described to correct the simple hollow back will not be of any use when the pelvis is inclined too far forward None of these exercises will help to elongate the flexors of the hips and the leg circling exercise described above will stretch the hamstrings still more In flexible cases having especially good powers of coordination, the subject will be able to correct the wrong tilt of the pelvis by

convex side, and this is what would be observed if the curve were due to unopposed action of the longitudinal muscles However, electromyographic studies have shown that in the majority of cases the muscles on the concave side are weaker than normal This is attributed to the fact that imbalance of the deeper muscles (semispinalis multifidus, and rotatores) is the main factor in producing the deformity These deep muscles are important rotators When those of one side are paretic, the unopposed action of the muscles of the opposite side rotate the vertebrae into a scoliotic position[29 30] (Fig 170) In some cases, however, the muscles on the convex side are atrophied and those on the concave side are contracted Changes then take place which

Fig 171 —Scoliosis due to unequal leg length resulting from poliomyelitis contracted in infancy A total right scoliosis is exhibited The right gluteal crease is 2 inches lower than the left the dimple at the posterior superior iliac spine is lower on the right and the right iliac crest and the anterior superior spine are low

cannot be explained on the basis of muscle imbalance alone [31] The complexities involved in scoliotic defects should make it obvious that physical educators and therapists should not attempt to correct them without the advice and guidance of a qualified physician

Lateral curvature lessens the ability of the spine to support the body weight distorts the body cavities and crowds the organs out of place and in advanced cases causes pressure on the spinal nerves where they pass out of the vertebral canal Scoliosis usually begins with a single C curve This may be to either side but since most people are right handed the muscles on the right side of the body are generally stronger and the convexity tends to develop

the extensors and flexors of the hips, and finally coming to the erect posture by extension of the lumbar spine

A combination of flat back and round shoulders gives the "gorilla type of posture, it is commonly seen in weak and fatigued cases

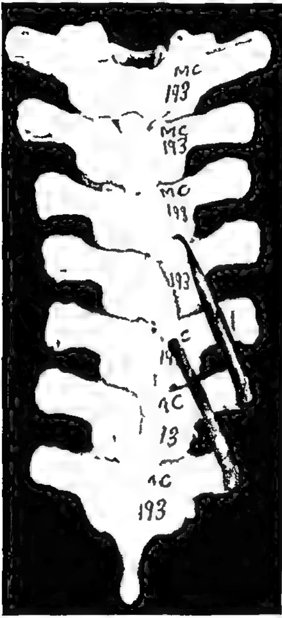


FIG 170 —The above illustration of a segment of the spinal column demonstrates the manner in which the unopposed action of the deeper muscles of the spine (semispinalis multifidus and rotatores) causes the vertebrae to rotate into a scoliotic position when the muscles of the opposite side are paretic (Allbrook)

Lateral Curvature Lateral curvature of the spine which in pronounced stages is called *scoliosis* is a sideward deviation It represents a combination of lateral deviation and longitudinal rotation One might expect that the muscles on the concave side of the curve would be stronger than those on the

in the erect position In our sedentary culture it is probable that people actually spend more time sitting than they do standing As in standing, seated posture is maintained by irregular volleys of action potentials but the furniture itself may force the body to assume one position or another Long continued poor seating habits may result in degenerative tissue changes and pain It is only within recent years that the study of anatomical and physiological principles and anthropometric data has provided a basis for the scientific design of furniture Among these data are the following

1 Frequent changes of position are important in preventing fatigue A chair should permit the sitter to move about, rather than restrain him in a given position

2 Comfort is at a maximum when the weight of the trunk is borne mainly by the ischial tuberosities The soft tissues of the thigh are incapable of

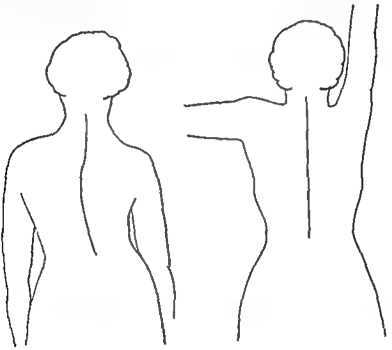


FIG 172 —Straightening a lateral curve by use of a key note position

affording good support They compress under the body weight affecting the muscles blood vessels and nerves, with consequent discomfort and possible numbness tingling or anesthesia A number of cases of thrombosis of the deep leg veins due to continued sitting during long automobile rides[32] or while watching TV programs[33] have been reported in medical literature

3 The height of the seat should be designed to prevent undue pressure on the soft tissue of the posterior aspect of the thigh It is generally recommended that the height of the seat be slightly less than the length of the lower leg when the foot is flat on the floor and the knee bent at a right angle Marked discom fort is caused by seats which are so high the sitter s feet do not reach the floor The depth of the seat should be such that the edge of the seat does not exert pressure against the back of the knee

to the left The condition tends to be more prevalent in girls and among ectomorphic types but is not confined to either The curvature may extend the whole length of the spine or it may be localized A C curve may tilt the head sideways in which case there is a reflex tendency to right it until the eyes are again level Over a period of time this righting reflex creates a reversal of the C curve at the upper spinal levels producing an S curve Further attempts at compensations may appear, creating additional undulations in the curve

In the early stages scoliosis may be *functional*, or *postural* These terms indicate that the curve can be obliterated by voluntary effort or by hanging from the hands In the later stages the condition becomes *resistant* or *structural* and the curve can no longer be so obliterated Many physicians classify all S curves as structural regardless of the degree of flexibility which they present Therapists and corrective physical educators should refer all cases of scoliosis to a physician before any attempt at correction is made Once a structural curve is established corrective exercises may produce a compensatory curve rather than an abolition of the primary curve [31]

Scoliosis may be caused by numerous unilateral conditions including the following

Hereditary defects in structure
Deterioration of vertebrae ligaments or muscles as the result of infections or diseases
Unilateral paralysis of spinal muscles
Unilateral short leg
Unilateral flat foot or pronation
Imbalance of muscular development as the result of occupation or habit

After ruling out the necessity for surgical or medical treatment the physician may refer scoliosis patients to a therapist or corrective physical educator for special exercises Correction of unilateral foot defects often eradicates functional curves and elimination of such habits as that of standing on one foot may be of value In schools physical educators should screen all scoliotic pupils for unilateral vision and hearing defects which may cause scoliosis and which require referral to medical specialists Seat and desk adjustments should also be checked

Key note Positions Cases of lateral curvature are so varied and the complications are so many that correction is largely an individual matter Key note positions have been much used for the correction of flexible cases The key note position is a device to help the subject in assuming the correct position When he tries to stand straight and shows a thoracic curve convex to left raising the right arm to a certain height may bring muscles into action that will pull the spine straight in some cases it may require raising both arms but to different positions when the curve is low it may require a sideward or diagonal position of one foot When a position is found that brings the spine to a vertical and straight position that is the key note position for that case The subject practices this position many times and he takes pains in returning to the fundamental position to hold his spine in the erect position if possible in this way he gradually acquires ability to assume the erect position at will (Fig 172)

Seated Posture Statements about posture usually refer to the individual

opposite direction Thus, postural defects are seen as total body phenomena tending to occur simultaneously at several levels

Posture is a dynamic, not a static concept The body is seldom stationary for more than a few moments often it is engaged in movements of greatly varying extent and direction The academic emphasis on static positions serves to simplify and clarify the explanation of postural mechanisms The understandings derived from a study of statics can be applied to the limitless number of dynamic situations of the body and the student should never be misled into forming a static concept of postural relationships

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19 Whitney R J Mechanics of Normal Muscular Activity Nature *181* 942–944 1958

4 Chairs should have a back rest providing support to the lumbar region of the sitter s spine in order that the lumbar erector spinae may be relaxed without full flexion of the trunk and undue ligamentous strain

5 Axiomatically the sitting worker s elbows should bear the same relation to his work table as they would if he were standing This height varies according to the work to be done and the amount of pressure it is necessary to exert For clerical work the forearms should be approximately horizontal [34]

The push and pull forces which can be exerted in seated positions have been carefully studied at the University of Michigan [35, 36] It has been shown that in addition to muscular forces such factors as bracing of the body inertia of body dead weight position of the body mass relative to its support, and friction between the body and the seat must be considered in any analysis of the principles of body mechanics The failure of earlier investigators to consider these points has resulted in considerable uncertainty regarding the application of their experimental findings to practical situations

Low Back Problem Medicine has been defined as 'a science that deals with the failure of adaptation of the human organism to environmental stress [37] One of the most common of these failures of adaptation results in the so called low back problem Of all the mammals only man shows evidence of lumbar breakdown but in him it occurs with distressing frequency A tilted pelvis places the lower lumbar vertebrae in such a position that compression forces tend to cause a superior vertebra to slip anteriorly over an inferior one The powerful erector spinae, the rectus femoris, the tensor fasciae latae and the ilio tibial bands act to bring the spine into hyper extension The principal muscles counterbalancing this effect are the abdominals which are usually weak from disuse With weak abdominals poor posture may result the lordotic curve is augmented the center of gravity of the body falls posterior to the bodies of the lower lumbar vertebrae and the tendency for the lumbar vertebrae to slip is correspondingly increased Injuries of this type almost always occur in the lumbo sacral area While the layman often speaks of sacro iliac strains the vertebrae of this area are so strongly held together that injuries of this type seldom occur to them Progressive resistance exercises designed to strengthen the back and abdominal musculature and to reduce the strength imbalance between the back extensors and the trunk flexors appear to provide relief from chronic, painful low back symptoms in a high percentage of cases [38]

Interrelationships of Posture Defects Although the subject matter of this chapter has been organized on a segment by segment basis for clarity of presentation the student of posture must integrate his thinking on a total body basis Muscles and ligaments are arranged so that they cross joints Any tension in them will cause an equal pull at both of their ends This arrangement may be likened to the links of a chain which forms an endless belt Under ideal conditions the various segmental tensions of this endless belt will be mutually neutralizing so that the parts of the body are held precisely in equilibrium The main force which can upset this equilibrium is gravity which pulls constantly downward Normally the downward gravitational pull on any body part is borne on the segment or structure immediately below it but if any body part deviates significantly from vertical alignment its weight must be counterbalanced by the deviation of another body part in the

opposite direction Thus postural defects are seen as total body phenomena tending to occur simultaneously at several levels

Posture is a dynamic not a static concept The body is seldom stationary for more than a few moments often, it is engaged in movements of greatly varying extent and direction The academic emphasis on static positions serves to simplify and clarify the explanation of postural mechanisms The understandings derived from a study of statics can be applied to the limitless number of dynamic situations of the body and the student should never be misled into forming a static concept of postural relationships

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Chapter 19

Walking, Running and Jumping

WALKING

Individual differences in walking appear as soon as a baby takes its first steps [1] In part, at least these differences are due to inherent structural features which are not under voluntary control and which limit the possible types of movement Elftman[2] lists three such features

1 Dimensions and configurations of the bones
2 Restriction of movement in the joints
3 Distribution of mass in the members

There is reason to believe that locomotion is an individual matter each person tending to assume a type which is the most efficient for his particular structure

In ordinary walking six distinct features require special attention (1) the contact of the foot with the ground (2) the position of the feet (3) the movements of the center of gravity (4) the transmission of weight stresses (5) the energy expenditure and (6) the muscular functions [3]

The heel usually strikes the ground first The body weight is then transmitted forward along the lateral periphery of the entire foot, and finally passes to the metatarsal heads as the step is completed The supporting phase of one leg largely coincides with the swinging phase of the other but there is usually a transitional period during which both feet are in contact with the ground The mechanical shock of the transfer of body weight from foot to foot is cushioned by a flexion of the knee

The majority of individuals toe out 7 5 degrees for each foot with a range from 10 degrees in toeing to 20 degrees out toeing apparently falling within normal limits This angle is believed to represent an adaptation of the body to the problems of support resulting from assumption of the vertical stance and the consequent elevation of the center of gravity It is produced by lateral or medial rotation of the thighs and may be different in each foot [3]

Progression is best measured by the movement in space of the center of gravity * since from it the velocity and acceleration of the body as a whole

* In man the height of the center of gravity is about 56 per cent of his height in women it is about 55 per cent of her height

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Progression is best measured by the movement in space of the center of gravity * since from it the velocity and acceleration of the body as a whole

* In man the height of the center of gravity is about 56 per cent of his height in women it is about 55 per cent of her height

can be computed In normal walking the center of gravity describes a sinusoidal curve in both the vertical and the horizontal planes The amount of vertical displacement is about 4 6 cm , the horizontal displacement is nearly the same Since these two displacements are about equal, the movement of the center of gravity in the body forms a figure of eight occupying approximately a 5 cm square [4] The longer the stride, the greater the movement of the center of gravity with each step

By translating the center of gravity through a smooth sinusoidal pattern of low amplitude the body succeeds in conserving energy The pattern is flattened by means of five separate but coordinated mechanisms

1 Pelvic rotation In walking the pelvis alternately rotates right and left This elevates the extremities of the successive arcs formed by the passage of the center of gravity

2 Pelvic tilt In normal walking the pelvis tilts downward about 5 degrees on the side of the non weight bearing limb This depresses the amplitude of the summits of the successive arcs

3 Knee flexion The body weight passes over the supporting leg at a time when the knee is being flexed The magnitude of this flexion is about 15 degrees The flexion also lowers the amplitude of the successive arcs

The total effect of this elevation of the extremities of the arcs by pelvic rotation and the depression of the summits of the arcs by pelvic tilt and knee flexion is to cause the sinusoidal curves to more nearly approach a straight line and thus materially reduce the range of flexion and extension which would otherwise be required at the hip joint

4 Foot and knee mechanisms As contact with the ground is made by the heel the foot is dorsiflexed and the knee joint is fully extended, so that the center of gravity attains its maximum depression As the weight passes on to the forefoot and the heel is raised the knee flexes so that abrupt inflexions of the arc of travel of the center of gravity are smoothed into sinusoidal waves

5 Lateral displacement of the pelvis Horizontal deviations of the center of gravity also aid in replacing sharp inflexions with sinusoidal curves in the horizontal plane This movement is greatly exaggerated in competitive walking in order to achieve a longer stride

It has been estimated[5] that the person whose work requires him to be on his feet takes 19 500 steps daily If he weighs 150 pounds, he will beat into his shoes about 3 000 000 pounds per day In walking at the rate of 120 three foot steps per minute one advances at the rate of 4 1 m p h Each foot is at rest on the ground for one half second then moves forward six feet and comes to rest again in the next one half second The moving foot passes the stationary foot at a maximum speed of about 12 8 m p h The maximum acceleration is approximately 3 7 g [6] Oscillations of the extremities are independent of oscillations of the body s center of gravity but are an important factor in the metabolic cost of progression

The optimal horizontal walking rate for women appears to be about 2 4 miles per hour [7] for men it is approximately 3 5 miles per hour [8] although various studies show slight deviations from these figures Walking at the rate of 3 5 m p h requires an energy expenditure of approximately 4 8 calories per minute [9] divided approximately equally between the movement of the leg

and the movement of the center of gravity There are rather large individual differences in energy cost however, since muscular training and efficiency, weight of clothing (particularly shoes) differences in posture, length of stride, frequency of stride, and rhythm of movement have been found to affect the energy expenditure [9]

The Kinesiology of Walking The sequence of muscle movement in the lower extremities during walking has been studied by use of the electrobasograph[11] and by the electromyograph [12] As the weight is transferred from the left forefoot to the right heel the muscles of the left leg except the tibialis anterior contract In the right leg the dorsiflexors (extensor digitorum longus tibialis anterior and extensor hallucis longus) and the tibialis posterior contract The former provide a controlled approach of the plantar surface of the

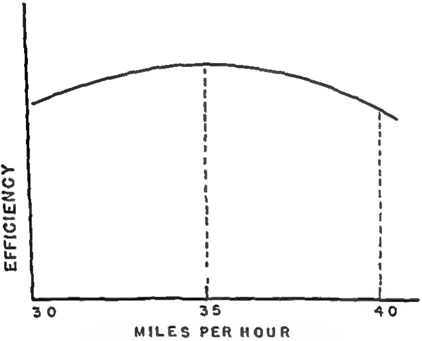

Fig 173 —Effect of rate on efficiency in walking

foot to the ground The contraction of the latter is responsible for the customary wear on the lateral side of the shoe heel Shortly after the heel strikes the ground the gluteus maximum begins to contract to prevent the pelvis from dropping forward As the left foot enters the swing phase it is held in dorsiflexion by the contraction of the muscles listed above in order to provide adequate clearance between the foot and the ground The forward swing of the leg is carried out by the hip flexors At the end of the swing the hamstrings act to halt the forward movement The extent of the rotation of the pelvis is largely controlled by the abductors and adductors As the weight on the right foot moves forward to the midtarsal region the tibialis anterior peronei and tendo Achillis contract and the tibialis posterior relaxes As the weight comes down upon the entire plantar surface of the foot the peronei tendo

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As the individual progresses the lower extremities alternate in their function, each in turn driving and supporting while the other swings forward

The force resulting from the extension of the driving leg may be broken down into three components a vertical component which acts against the pull of gravity and supports the body, and two horizontal components One of these acts in the direction of progress, and the other, which is relatively insignificant, acts at a right angle to the preceding component When one foot is on the ground it supplies a small force in the medial direction This component will not be included in our discussion

These are the simple mechanical features characteristic of our forward progression Needless to say this brief analysis is inadequate It is necessary to study each individual movement made by the body, when walking or running in order to understand its contribution to the entire activity

Forward Inclination of the Body Immediately before stepping forward the trunk is inclined toward the direction of progress The purpose of this forward inclination of the trunk is to place its center of gravity more nearly

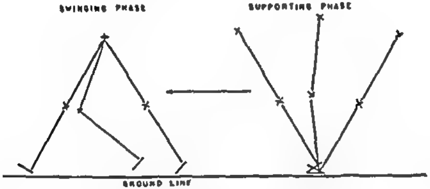

FIG 175 —Diagrammatical representation of the action of the leg in the swinging and supporting phases, while walking

in a direct line with the force exerted by the driving leg In this way, man is better able to overcome air resistance and the inertia of the trunk If he fails to incline the trunk forward he finds that the leg drive will carry the lower portion of the trunk forward well enough The center of gravity of the trunk however is above and behind the force exerted by the driving leg therefore the inertia of the body is not overcome directly, and in effect will exert a torque about the hips in the reverse direction This will tend to cause a person to fall over backward

The faster a person intends to walk or run the greater should be the inclination of the trunk This is because the major horizontal component of the force supplied by the driving leg is relatively greater as compared to the vertical component (Fig 174) Similarly, it will be found necessary to bend well forward when walking into a strong wind Here again the major horizontal component of the driving force must be increased in order to overcome the great increase in air resistance In each case the increased forward inclination brings the center of gravity of the trunk more nearly in line with the driving force

Achillis and extensor digitorum communis are in contraction partially to prevent dorsiflexion of the foot Further contraction of the gastrocnemius and soleus, assisted perhaps by the other plantar flexors, provides the force to elevate the heel and the weight shifts on to the forefoot As the metatarsals strike, the abductor hallucis and flexor digitorum brevis begin to contract although their action is not yet clear The peronei and extensor digitorum place the foot into valgus as a preliminary to the transfer of the weight from the lateral to the medial side, while the extensor digitorum communis opposes the tendency for plantar flexion of the toes The body weight is now transferred from the great toe of the right foot to the heel of the left foot and the cycle of muscular contraction and relaxation is resumed

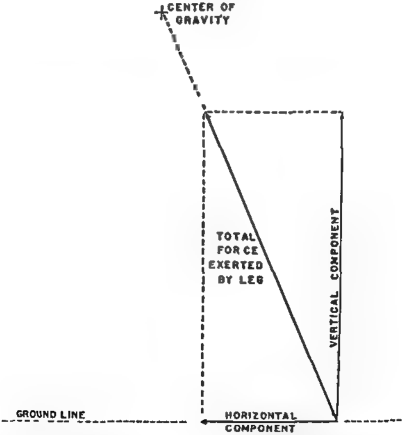

FIG 174 —The total force exerted by the driving leg while walking and its relationship to the center of gravity of the body The two major components are shown

Mechanics of Walking Essentially man propels himself forward by alternate and rhythmical drives from the legs The body is inclined forward immediately after which the driving or supporting leg extends and pushes the trunk forward When the forward motion of the trunk brings its center of gravity past the forward edge of its supporting base (the toes of the driving foot) the pull of gravity tends to cause the body to fall forward and downward At this point the other leg is swung forward and placed on the ground This supplies a much wider base for support and saves the body from the fall

momentum of the leg associated with extension of the knee Just before contact with the ground, torque may be exerted by the hip extensors to slow down the forward swing

At the start of the forward swing the hip, knee and ankle are all in complete extension As the leg swings forward, flexion of all the joints increases, especially at the knee and ankle This flexion at the knee and ankle is in order that the foot will not scrape on the ground When the foot has passed under the body, the hip of course, continues to flex, but the knee extends This is not necessarily an active muscular extension, the momentum of the leg, coupled with the slight restraint exerted at the end of the swing by the extensors of the hip acts to extend the knee When walking rapidly or running the swinging phase requires less time and the extensors of the knee function in order that the knee be extended when the heel strikes the ground The ankle extends slightly after passing under the center of gravity and is near its normal position when the heel strikes the ground

Combining the Swinging and Supporting Phases While the leg supports the body and propels it forward the other leg swings forward to make contact with the ground When walking the time required for the swinging phase never exceeds that needed for the supporting phase When walking slowly, there will be an overlapping of the two phases and both feet may be on the ground as much as 30 per cent of the time As the speed is increased the supporting phase is shortened far more than the swinging phase, and the period of overlapping or double support decreases or vanishes completely When the time required for the supporting phase becomes less than that required for the swinging phase the swinging phases overlap and there will be a period when both feet are off the ground At this point the individual has ceased to walk and has commenced to run

Vertical Movements of the Pelvis Because the legs alternate rhythmically with periods of support and non support so the pelvis finds itself supported alternately first on one side and then on the other If progress is slow, there will be periods when it is supported on both sides Because the extent of support depends upon speed of progress it is difficult to provide an accurate description of the vertical movements of the pelvis when walking The pelvis is at its highest point on the supporting side when the center of gravity is directly over the point of support The lowest point is found in the forward swinging phase of the leg just before the foot strikes the ground Intermediate conditions are dependent upon the length of the period of double support

Rotation of the Pelvis and Legs When the swinging leg advances the pelvis on the same side is carried forward to a greater degree than it is on the opposite side When the other leg swings ahead the situation is repeated but the opposite side is involved The amount of rotation produced in this manner will vary greatly but the width of the pelvis and the speed of walking or running are major factors

When the leg swings forward and that side of the pelvis moves forward and rotates the foot should rotate inward This does not happen in normal walking the toes always pointing straight ahead Therefore the thigh must be rotated outward along with the forward swing Likewise after the foot contacts the ground there is an equal amount of inward rotation during the supporting phase to compensate for the opposite rotation of the pelvis

The Supporting or Driving Leg—The First Step When the center of gravity of the trunk has moved forward to the optimum position which in very slow walking is a little back of the line of force to be exerted by the driving leg but advances as the *speed of walking is increased, the leg is* extended at the hip knee and ankle (Fig 175)

The vertical component of force serves to support the body against the pull of gravity and the horizontal component propels the body forward the two acting together accelerate the trunk forward and upward During forward progress the foot is fixed the pelvis moves forward and the angle the leg makes with the ground decreases The force exerted by the leg changes as the leg approaches complete extension and the relative magnitudes of the horizontal and vertical components also change

Once the body is in forward motion the second and subsequent supporting phases differ only in that the supporting phase starts when the swinging leg strikes the ground The force exerted by the leg at this point also may be resolved into two components As before, the vertical component supports the body as soon as contact is made with the ground but the horizontal component acts as a slight restraint to forward progress and slightly reduces the efficiency of the operation With the forward movement of the body this restraining force becomes progressively smaller and finally disappears when the center of gravity of the trunk is directly over the point of support *The point of support, however is indefinite, shifting* from the heel to the ball of the foot as the trunk moves forward This restraining force may assume great magnitude when one wishes to come to a sudden stop

When the supporting leg first makes contact with the ground, it is in almost complete extension, but flexes slowly until the center of gravity of the trunk is directly over the point of support At this point extension begins and continues until the supporting phase is terminated

Extension occurs at the hip, knee and ankle Ankle extension is delayed somewhat but persists longer than at the knee When the heel lifts from the ground the knee is usually completely extended, but the foot and ankle continue to act Extreme extension (plantar flexion) of the ankle acts to lengthen the supporting leg and by transferring the supporting area from the heel to the ball of the foot permits the time the force is exerted by the leg to be longer than otherwise

Action of the Swinging Leg Upon completion of the supporting phase the leg is lifted and swung forward in order to initiate a new supporting phase The Weber brothers taught that the swinging leg acted as a pendulum in its forward motion The fact that the knee flexes in the forward swing is sufficient to invalidate the pendulum concept Studies on the acceleration of the limb by Braune and Fischer and later by Fenn[13 15] and by Elftman [2 16 18] definitely show that the leg does not act as a pendulum In the case of running the torques exerted by the hip flexors during the first third of the forward swing are large The forward swing of the leg starts with hip and knee flexion As the speed of walking or running is increased so is the torque at the hip increased because the speed of the forward swing is largely dependent upon the magnitude and duration of the torque exerted by the hip flexors From the point when the thigh is vertical until near the end of the forward swing the thigh swings freely at the hip except for the impetus provided by the

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Pelvic rotation has been emphasized by coaches of competitive walking and running and is commonly referred to as "hip roll An optimal amount of hip roll improves running efficiency by increasing the length of stride and the duration of application of force by the driving leg

Movements of the Shoulders, Arms, and Head When one side of the pelvis moves forward during the swinging phase the shoulders on that side drop back to compensate for pelvic rotation The arms also swing in opposition to movements of the leg The action of the arm in the anterior posterior plane serves to reduce the rotation of the shoulders This can be demonstrated by holding the hands against the thighs while walking and noticing the increased swing of the shoulders By reducing the swing of the shoulders the arms indirectly aid in keeping the head facing forward otherwise the rotators of the head and neck would do an enormous amount of work

The arm swing tends to be across the body to a slight degree This is exaggerated if the individual is short and broad shouldered The sideways movement of the arms helps to compensate for the sideways movement of the body caused by the swinging legs and by the fact that the body is supported first on one side and then on the other When walking slowly the arms swing loosely at the sides and only a little muscular effort is employed As speed is increased so is the frequency of the arm swing and the action becomes much more vigorous and complex With increasing speed, there is an increasing tendency to drive the arms with greater violence and the elbow is bent in order to shorten the arm and make possible the faster alternating movement which is required

Arm action like leg action, is sometimes modified in special forms of marching Soldiers of the English army are taught to use an exaggerated arm swing and those of the German army are taught an exaggerated leg movement the so called goose step These movements are mechanically inefficient but are employed when show or ceremony are more important than efficiency Extensive movements of this type form a direct contrast to the contracted arm muscles and restricted arm movements seen in a runner who is tieing up as a result of fatigue but both decrease efficiency by interfering with the normal balance and respiratory mechanisms as well as by requiring energy to contract the muscles

The head does not move forward at the same velocity as the trunk, its velocity being slightly less than the trunk when the body is driven forward by the leg and slightly greater when no propulsive force is being exerted These fluctuations in head velocity are negligible when walking but increase to a marked degree when running

Pathological Gaits Paralysis or other causes of deficiency in tone in certain muscles often result in characteristic types of pathological gaits This can be touched upon only briefly here students desiring more detailed information on such disabilities are referred to the texts by Steindler [19, 20]

Paralysis of the Gluteus Maximus Shortly after the heel touches the ground a backward thrust of the trunk begins This is completed at the end of the stance period Its object is to move the center of gravity behind the hip joint and thus prevent jackknifing of the joint

Paralysis of the Gluteus Medius When the affected leg swings forward the trunk is swayed to the sound side so that the swinging leg may clear the

ground. During the supporting phase the pelvis drops to the sound side. To offset this the trunk is swayed to the affected side.

Spastic Gait. Contracture of the muscles hinders the rhythmic shortening and lengthening of the legs and the forward and backward swing of the limbs. The hips become locked and stability is further disturbed by adduction and inward rotation at the joint. The patient may walk primarily on his toes (spastic equinus gait) or on his heels (spastic calcaneus gait).

RUNNING

When the speed of locomotion exceeds 4 m.p.h. a running gait becomes less fatiguing than the forced rate of walking, although the energy consumption is increased. This results largely from the fact that a greater part of energy expended in raising the body is utilized in propelling the runner forward than is true in the case of the walker. There is an additional saving in the reduction of arm and shoulder movements. Morton and Fuller[21] have utilized data collected by the Harvard Fatigue Laboratory and the Laboratory of Physiological Hygiene of the University of Minnesota to compute the metabolic cost of walking and running at various speeds (Table 16).

In running, of course, there is no optimal speed. By the very act of breaking into a run the subject has exceeded the most economical rate of horizontal locomotion, and the energy expenditure increases as the speed increases. A series of studies by Fenn,[13-15] whose findings have been confirmed by Elftman,[16-18] determined that in running at maximum speed the legs work at the rate of approximately 2.95 h.p. His calculations are summarized in Table 17.

TABLE 16.—Energy Cost of Walking and Running

Method and Speed	*Cal./Hr.*	*O_2 Used Liter/Hr.*
Walking		
2.3 m.p.h.	210	43
2.9	250	51
3.2	270	55
3.5	290	59
4.0	350	71
4.6	470	96
Running		
5.7	720	147
6.9	870	178
11.4	1300	265
13.2	2330	477
14.6	2680	547
14.8	2880	588
Sprinting		
15.8	3910	798
17.2	4740	967
18.6	7790	1590
18.9	9480	1935

TABLE 17 —Energy Consumption in Running (Figures in Horsepower)

Chemical Energy from Oxygen Consumed			13 00
Energy of Anaerobic Phase of Muscle Contraction (40% of Total Energy)		5 20	
Waste in Recovery		7 80	
Total		13 00	13 00
Energy of Anaerobic Phase of Muscle Contraction			5 20
Total Useful Work in Propulsion (22 7% of Total Energy Expenditure this figure may be 10–15% too high)		2 95	
Acceleration of Limbs (12 9% of Total Energy Consumption figure may be 10% too low)	1 68		
Deceleration of Limbs (40% of Acceleration figure may be 9% too high)	0 67		
Maintenance of Velocity	0 50		
Overcoming Gravity	0 10		
Total	2 95	2 95	
Fixation Energy, Waste Heat Frictional Loss Vertical Movements of the Body Changes in Horizontal Velocity Wind Resistance Side wise Movement Movement of the Shoulders etc		2 25	
Total		5 20	5 20

In spite of these impressive figures and in spite of the fact that man is characterized by a comparatively low crural index (ratio of the length of the lower leg to that of the thigh) which theoretically better fits him for running than for jumping [22] as a running animal man falls into the slower group *Just how important variations of the crural index are to runners is yet to be* determined

The essential difference between walking and running is the absence of a period of double support and the presence of a period of non support when neither foot is in contact with the ground (Fig 176) In order to achieve the increased speed characteristic of running far more force must be exerted in *the direction of progress The vertical force is also increased* but not to as great an extent In order to accomplish this the angle which the leg makes with the ground during extension is smaller and the pelvis is necessarily carried lower

The additional force supplied by the extensors of the driving leg at this new angle both requires and produces several changes in the mechanics of running when compared with walking Then too it must be recognized that running speed may vary from the slow jog to the extreme effort of the sprinter and that the mechanical patterns will not be alike

The lower position of the pelvis necessitates greater flexion of the knee of the supporting leg when the center of gravity of the trunk passes over the point of support This increased flexion of the knee makes possible a more

powerful extension of the driving leg The greater drive of the leg increases the length of the stride The increased speed coupled with the period of non support should result in a greater impact when the foot of the swinging leg strikes the ground To minimize the shock, the swinging foot does not meet the ground with the heel as in walking The leg reaches full extension

FIG 176 —Middle distance runners demonstrating the period of non support

and appears to have started back before contact is made with the ground This change of the angle of impact permits the first contact with the ground to be made by the ball of the foot This of course, cushions the shock and to some extent reduces the restraining force, because the center of gravity is more nearly over the foot at the instant of contact than would otherwise

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be the case The greater the speed of running the less the amount of restraint caused by the contact of the foot of the swinging leg

As the center of gravity of the body passes over the supporting leg the heel of the foot may or may not be pressed to the ground Slow running usually finds the heel on the ground whereas in the case of a sprint, the heel may not touch the ground at any time

When the supporting leg reaches complete extension and the foot is lifted from the ground, the knee is flexed far more than when walking and the foot is brought up quite high in the rear This, in effect, serves to shorten the swinging leg and reduces the amount of force needed to bring the leg forward As a result, the runner exerting his maximum effort can swing the leg forward much faster and greatly increase his speed This is important because the duration of the forward swing of the leg may be a limiting factor on total speed Increased flexion of the knee is also necessary to provide for clearance for the swinging leg needed because of the lower position of the pelvis

The arm action serves the same purpose as in walking but it must be done with far greater speed in order to keep in phase with the faster movement of the legs This is accomplished by a great increase in muscular effort and by bending the arm at the elbow Like flexing the knee in the swinging phase of the leg, flexing serves to shorten the arm and permit greater speed The tendency to draw the arm across the body increases with the speed

The mechanical features of running like walking may undergo considerable change with changing speed That there will be differences in the form used by marathon runners and sprinters is obvious Endurance being a major factor for successful performance, the distance runner is greatly concerned about economy and must adjust his style and pace to provide for the greatest efficiency Sprinters on the other hand, do not exhaust themselves after 100 yards They give little thought to the matter of efficiency from the standpoint of energy utilized and may make great sacrifices in economy to gain a little added speed

Sprinting It is important to get away to a fast start under racing conditions A yard lost at the outset of a race because of a slow start must be made up an unlikely event in a short race if the contestants are evenly matched A short reaction time and great driving power are the chief natural prerequisites for a quick start Good technique enables the athlete to capitalize on these advantages Two artificial aids are employed the spiked shoe and the starting block The spiked shoe provides a firm base for the driving leg so that the magnitude of the horizontal component of force will not suffer because of inadequate traction The starting block or holes dug in the track serve the same purpose for the initial drive

In the crouch start the low position of the body makes it possible for the horizontal component of the driving force to be greatly increased because the body is more nearly directly in line The legs can also provide a stronger drive upon extension from this position because the gluteus maximus is brought into play This is the result of hip flexion This muscle does not act to extend the hip when the body is more nearly erect

When the sprinter is on his mark his weight is largely supported on his feet and one knee His hands are on the starting line and a little weight is

supported by the thumb and fingers The position of the feet is not exactly prescribed Considerable latitude is permitted in their distance from the starting line Selection should be governed by ascertaining which stance produces the fastest start for a given individual This is determined by the energy supplied by the combined efforts of the legs The force exerted against the ground and the length of time it is applied are the determining factors The front leg seems to exert about the same amount of force for the same amount of time regardless of position As the position of the rear foot is moved back the force it can exert is increased but its duration will be reduced Optimum conditions for the individual are a matter of trial and practice The proper balancing of these factors against each other makes it possible to achieve the fastest start Investigations by Henry[23] indicate that for most individuals optimum results are achieved when the spacing between the sprinter s feet at the start lies between 16 and 21 inches Laterally the feet should be spaced about 7 or 8 inches apart to avoid loss of balance and to insure a direct drive from the feet to the pelvis

FIG 177—The start of a sprint race Extension of the driving leg is not complete Observe that one team starts with the right foot on the rear block and the other uses the left foot

The *get set* position elevates the hips to the optimum position where the legs can exert their most effective drive The height will vary depending upon the position of the feet but will always be higher than the shoulders Upon starting the sudden extension of the hips will elevate the shoulders throw the center of gravity ahead of the feet and drive the body horizontally rather than vertically

When the race starts the sprinter drives as hard as possible with both legs It is essential that the first few strides be relatively short and made with all the force possible in order to provide the needed acceleration to reach top speed quickly The body gradually rises until full speed has been reached at which time most sprinters lean forward about 20 to 25 degrees This keeps the center of gravity ahead of the feet and simultaneously reduces the air resistance

The remainder of the sprint has already been described except that a few features of running are exaggerated in order to gain top speed Flexion of the knee in the swinging phase is increased in order to increase the speed of the

forward swing The swinging leg is often well on its way back when the foot strikes the ground contact being made when it is directly under the center of gravity This eliminates the restraining force present in the walk or slow run When the toe of the swinging foot touches the track the ankle flexes and the heel nears the ground Force comes from extension of the knee and especially the ankle This is applied as soon as the foot strikes the ground and is continued until the foot is lifted Speed is increased by increasing the length of the stride, rather than the speed of leg movement alone, but after the optimal length of stride is achieved, any further extension will result in a reduction of speed

The leg functions as a third class lever, with the fulcrum at the hip joint The leg is pulled forward by the thigh flexors and backward by the glutei and hamstrings The quadriceps and the triceps surae act to extend the knee and ankle respectively The complex workings of the two joint muscles, as exemplified in Lombard s Paradox (p 253) increase the efficiency of these movements If the toe flexor muscles are sufficiently developed, they can contribute significantly to the final phase of the propelling force If they are flaccid, the result is, in effect like reducing the length of the stride by an amount equal to the length of the toes

Middle Distance Running From the standpoint of the kinesiologist middle distance running does not differ greatly from sprinting The need for a fast start is almost as great when running 440 yards as it is when running 220 yards The same principles apply in each case The middle distance runner breathes during the race which is not necessarily true of the sprinter in the 100 yard dash This results in less fixation of the respiratory muscles

The cadence of the middle distance runner is slower, consequently there may be less heel lift in the swinging phase of the leg and the knees are not lifted as high The arms are not so tense and need not be flexed as much The slightly slower speed permits the body to be carried more nearly erect say at an angle of about 15 degrees which also aids respiration The drive from the legs being less all the factors which contribute to the sprinter s great speed are given slightly less emphasis but attention is devoted to keeping vertical movements of the center of gravity as small as possible while striding

Newton s First Law of Motion indicates that changing the speed, regardless of whether it is increased or decreased, requires an expenditure of energy It would thus appear that the middle distance or distance runner should immediately establish his optimal pace and maintain it unchanged throughout the race Theoretically at least a strong finishing kick would seem to be an expensive use of energy which might have been more effectively applied another way However Bannister[24] has pointed out that in middle distance racing runners seem to achieve their best times by running the first part of the race considerably faster than the latter part He suggests that the explanation may lie in the fact that the muscle pH falls as lactate accumulates, and this may affect the efficiency of the aerobic mechanism Another factor may be the motivational or psychological state of the runner at various times in the race Ideal pacing patterns must also be modified for strategic purposes such as jockeying for position on a turn

Distance Running In track events such as the 2 mile run endurance and muscular efficiency are of major importance The energy consuming start

of the sprinter is not necessarily desirable since a yard or two lost at this stage of the race may be regained later without too much expenditure of energy Relaxation rhythm and adequate respiration are essential for effective distance running

Because the leg drive is less, the trunk is carried more nearly erect than in the shorter runs When the leg swings forward the heel is not lifted quite as high as when running the shorter distances The foot is often brought into contact with the track with the weight almost evenly distributed between the ball of the foot and the heel

The distance runner endeavors to conserve his energy in every possible way The arms are flexed less and swing loosely There is little if any fixation of the shoulder muscles The runner does not ordinarily consciously endeavor to greatly increase his stride but moves as easily as possible A unique feature of the marathon and other runs of great distance is the fact that the athlete may be given candy, orange juice or other nutrients as he runs in an endeavor to replace the energy used in the race

JUMPING

The Broad Jump The goal of the broad jumper is to propel his center of gravity horizontally through the air as far as possible Since the distance of the jump is directly proportional to the energy of projection maximum speed at the take off would be desirable but the necessity for changing the direction of movement demands a momentary stabilization of the body at the point of the change and this can be accomplished only by a reduction of speed The forceful beat on the take off board required to implement Newton s Third Law may further reduce his speed—and may also result in a tendency to incur heel bruises In theory the body should be propelled into the air at the optimum angle of 45 degrees Actually most jumpers take off at an angle of about 25 degrees and there are some students who feel that the body cannot develop sufficient power to attain the theoretically optimum angle and still project itself forward to any distance However the theoretical calculations made by Cureton[25] and by Bunn[26] support the theory that a higher angle than is customarily used would be advantageous

As the jumper approaches the take off board the knees are a little bent and he is in a slight crouch (gather) At the take off the extensors of the hips knees and ankle are forcefully contracted The amount of elevation and distance achieved may be increased by a forceful upward swing of the arms and the leading leg since the mass of these limbs times their velocity produces a momentum which may be transferred to the body to assist in propelling it through the air * To increase this advantage the ancient Greek jumpers held weights (haltēres) in their hands

Once the runner has left the ground there is nothing he can do to increase

* The kinetic energy expended in jumping can be roughly calculated by the formula

$$KE = \frac{1}{2} mV^2$$

where

KE = kinetic energy
m = mass of the body moved (weight/gravitational acceleration)
V = velocity

Calculations of the distance to be travelled by the body for given angles and velocities require the application of trignometric formulas

his forward acceleration but he can affect the distance achieved by changing the configuration of his body and the relative position of the partial masses A hitch kick will not increase momentum, and the legs cannot develop enough resistance against free air to enable the runner to increase his distance by continuing his running motions after the take off However such movements may rotate the hips backward and give a greater forward reach with the legs Whether this will actually increase the distance jumped is a matter of dispute

FIG 178—Good form in the broad jump demonstrated by Willie Steele San Diego State College National and Olympic Champion with a mark of 26 feet 6 inches

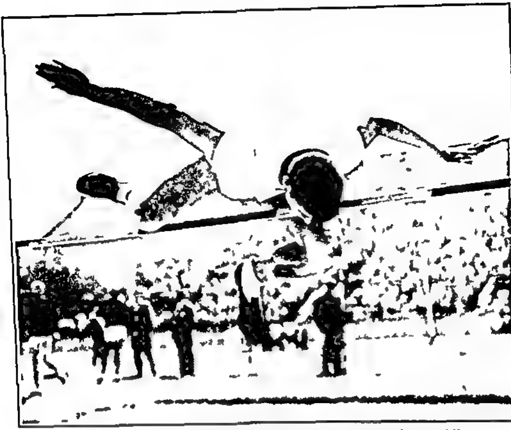

FIG 179 —George Stanich clears the bar in the high jump using the straddle variation of the Western style (Photo courtesy of Thomas McDonald)

While still in the air, the athlete must prepare to land (Fig 178) The legs are brought forward and the arms down and back This inclines the trunk forward so that the center of gravity is a little above the trajectory of the feet and there is less likelihood of the jumper falling backwards when he lands When the actual landing takes place the hips and knees are flexed to absorb the shock and the jumper rocks forward onto his hands and knees

The High Jump In contrast to the broad jumper, the high jumper must propel his center of gravity vertically as far as possible For this he need not have unusual horizontal speed since his success will depend largely upon his height (his center of gravity is higher to begin with) and an unusual amount of leg spring He needs only sufficient horizontal speed to carry him across the bar The theoretical effects of distance of take off, angle of take off, velocity time in the air energy and other factors for various heights of the bar have been calculated by Cureton [27]

Three styles of high jumping may be observed the scissors, the Eastern style the Western roll and their variations The following descriptions assume that the athlete takes off from his left foot, as is customary for right handed men

When executing a *scissors* jump the approach to the bar is made from the right and at an angle of about 45 degrees About 8 or 10 steps are all that are needed to insure sufficient horizontal speed The take off made by the left foot is at a point a little over 3 feet in front of the bar The first 6 steps are

made at moderate speed and the last 2 are slightly slower because it is here that the athlete adjusts for the final spring The last stride may be a trifle longer and the body is carried somewhat lower in order to *gather* for the jump and to get a good swing with the right leg When the center of gravity is directly over the left foot, which strikes the earth flat footed and quite hard the vertical drive is given and the right leg is thrown upward as far as possible The flat footed take off and bent knee due to the lowered body, permits powerful extension of the knee and ankle and projects the body vertically into the air When the hips reach the height of the bar the extended right leg is thrown over the bar and as it descends is followed by the now extended left leg It is this scissors action of the legs which gives the style its name

Before the mechanics of the high jump received much study the scissors jump was executed with the trunk of the body nearly erect or leaning forward a few degrees It is obvious that the center of gravity of the body need not be lifted so high above the bar Too much energy is wasted in doing needless work and this style is now seldom used in competitive jumping The *Eastern* form gains greater height with the same amount of effort As the athlete s foot leaves the ground, the hips are extended and the trunk dropped backward to permit the leading leg to be thrown upward and the hips lifted over the bar At the same time the opposite arm is swung forcefully upward to aid in lifting and rotating the body The knee of the jumping leg is tucked under to permit the body to rotate faster The athlete s body clears the bar almost as if he were lying on his back with his body nearly horizontal The center of gravity is only a little above the bar and no energy is wasted doing unproductive work By modifying the scissors style in this way greater height can be reached with the same force

The jumper usually lands on his left side because the final scissors action of the legs tends to rotate the body on its longitudinal axis so that he faces the bar as he passes it in his descent

The difficulty with the Eastern style is that the jumper must travel some distance horizontally in order to get his body over the bar To overcome this the *Western roll* was introduced In this style the bar is approached at an angle of approximately 45 degrees from the left Again only 8 to 10 strides are required The speed is not great and the last two strides are used to make the necessary adjustments to get perfect coordination and spring The position and initial portion of the take off are about the same as for the scissors When the jump is made the right leg and left arm are thrown high into the air Their momentum is a great aid in getting added lift During the ascent the left leg is lifted and flexed but the right remains extended The upward swing of the right leg must be very vigorous because its momentum not only aids the lift but also supplies the energy required to turn the body on its longitudinal axis as it passes over the bar The arm head and shoulders rather than the leading foot pass over the bar first (Fig 179) The right leg is in complete extension and the left leg is drawn up and flexed as the athlete rolls over the bar on his left side

The body is flexed at the hips just before the bar is cleared but straightens out when passing over the bar When the jump is executed in good form the body is as nearly horizontal as possible as it passes over the bar with slight and uniform clearance the entire length of the trunk The left arm and the

head and shoulders are dropped as soon as possible in order to provide a little lift for the hips as they clear the bar This is the part of the body most likely to touch In order to land safely, advocates of this style throw the flexed left leg forward turn, and break their fall with the left leg and arm

When clearing the bar some jumpers rotate the body earlier than others and pass over the bar facing downward During the descent the flexed right leg is thrown forward and the landing is ordinarily made face downward with the right leg and arm absorbing the shock This belly roll style gives a slightly greater lift and is considered by students of body mechanics to be the most efficient form yet devised other than diving over head first (Fig 180)

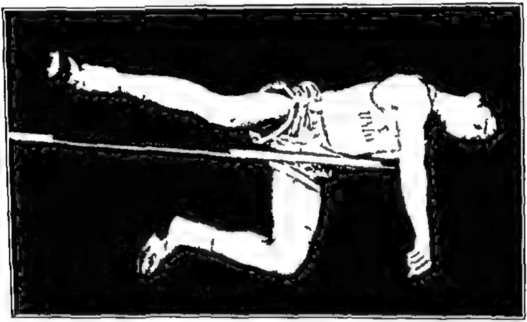

FIG 180—John Thomas clearing the bar at 7 feet in straddle roll style This athlete weighs 185 pounds and is 6 4½ tall The length of his leg bones is an important factor in his success as a jumper, since the amount of work which a muscle can perform depends upon the number and size of its fibers and the distance through which they can contract (Photo by Boston University Photo Service)

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Chapter 20

Kinesiological Principles in Sports and Games

KINESIOLOGY finds its greatest practical applications in the fields of athletics time and motion study, and the various services in physical medicine and rehabilitation While the problems confronting the coach and the therapist are basically the same—that is teaching the individual to make the most effective use of his bodily machinery—the methods of solving them may be very different It is doubtful whether a corrective therapist a physical therapist or an occupational therapist is likely to hinder a patient s recovery by too much emphasis on kinesiology whereas many a coach has completely disorganized an athlete s performance by injudicious emphasis on specific muscle actions

LIMITATIONS OF KINESIOLOGY IN COACHING

As both Jackson and Beevor emphasized (Chapter 1, p 25), it is movements, not muscles which are represented in the higher nerve centers The high jumper for example must concentrate only on propelling his body over the bar The minute he begins to think of contracting the gastrocnemius soleus of the take off leg to lift himself by their action on the ankle lever he is no longer thinking of his prime objective (Fig 181) The result will probably be confusion and failure[1] It is an important kinesiological principle that the coach should seldom if ever emphasize the contraction of specific muscles when guiding athletes although his teaching is more effective when his advice is based on such specific knowledge

Neither should the coach err in the opposite direction and be too general in his admonitions For example the tennis teacher s order to hit the ball harder may be quite ambiguous to a novice who is already stroking as hard as he can It becomes meaningful to the learner when the coach is precise in his instructions calling attention to the need for a longer preliminary backswing a more definite step into the ball and an attempt to stroke *through* the ball instead of chopping at it The instructions then become specific and meaningful from the learner s point of view although the coach may have derived his advice from a formal study of anatomy kinesiology, and body mechanics

If a knowledge of academic kinesiology were necessary for the learning of motor skills, no baby would be able to learn to walk Motor skills can be acquired at highly effective levels by performers who are uninformed of the subject matter of kinesiology Often great athletes have stopped to analyze their performance only after winning championships In many cases they have

FIG 181 —George Stanich of the United States Olympic Team takes off in the high jump (Photo courtesy of Thomas McDonald)

given false and even absurd explanations of what they do and how they do it. For instance, champion tennis players have taught that in the forehand drive the axis through the shoulders should be at right angles to the net at the moment when the ball is contacted, although motion pictures reveal that they themselves rotate the *shoulder* axis back to a position parallel to the net and that at the moment of contact they are already beginning to return to center-court position (Fig. 182). Such examples illustrate both the ease of making

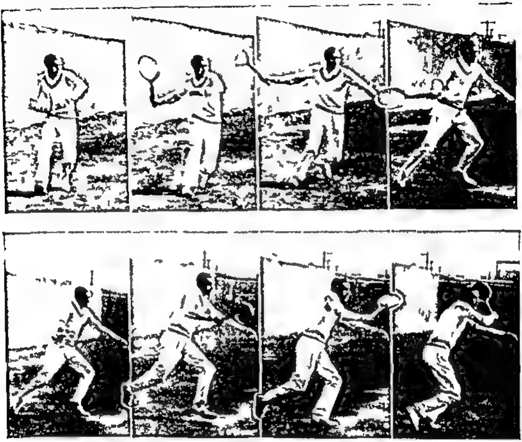

Fig. 182.—Tilden forehand drive. (Courtesy of American Lawn Tennis, Inc. From *Mechanics of the Game of Lawn Tennis*, Vol. II, by J. Parmly Paret.)

errors in kinesiological explanations and the fact that effective functioning may occur without a formal knowledge of such principles if the other conditions of learning are adequate.

APPLICATION OF KINESIOLOGY TO COACHING

Even though kinesiological analysis is not essential to effective functioning, it does not follow that kinesiology has no contribution to make. Knowledge and application of kinesiological principles can make important and crucial differences in learning. The problem is to determine what kinesiological knowledge to select and how to apply it in a given teaching situation.

Much of the information in this text consists of formal background knowledge, some of which is not directly applicable in the form presented. At the practical level kinesiological knowledge is a professional tool which can be

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FIG 181 —George Stanich of the United States Olympic Team takes off in the high jump (Photo courtesy of Thomas McDonald)

applied to human motion More advanced mechanical analyses of a tremendous variety of sports skills have been published, or are available as graduate theses Many of these are cited in Bunn's text,[2] which makes its own extensive contribution to this field

A knowledge of mechanics is particularly important to physical educators A good physical education program includes such a tremendous variety of activities that no one teacher is likely to be able to obtain personal performance experiences in all the activities he will be called upon to teach Mechanical analysis gives him a sound basis for intelligent coaching in the less familiar activities

Analyzing the Internal Mechanics of the Performance Internal mechanics refers to the bone muscle leverages stress resistances of the various body tissues, internal friction range of movement, and numerous other intra organismic workings The significance of internal mechanics is equal to that of external mechanics but the body acting on information fed back through the proprioceptive and kinesthetic mechanisms, tends to make automatic or sub rational adjustments in internal mechanics Therefore, coaching attention is more often devoted to external mechanics than to internal mechanics

Assessing the Kinesiological Requirements of the Activity For successful performance each separate motor skill demands its own combination of kinesiological abilities and characteristics Considerable body mass for example is a necessity for inside line play in football but it is a hindrance in gmynastics Both activities require great strength but this should be predominantly in the legs for football and in the arms for gymnastics

Guilford[3] has emphasized the need for studies of the intercorrelations between anatomical and psychological traits He considers that a fuller understanding of the properties of bone and muscle and the manner in which they are put together might go far to explain psychomotor abilities Neurological parts and properties might also account for many of the observed distinctions Known psychomotor factors appear to include two general factors strength and impulsion (rate at which movements are initiated from a stationary position) and several specific factors among which are speed (rate of movements after they have started) static precision dynamic precision coordination and flexibility These may represent a simultaneous involvement of two or more regions Muscular endurance circulatory respiratory endurance, agility, and power appear to be primary psychomotor abilities but it is possible they are syndromes of physiological characteristics A wise coach must understand that a myriad of physical factors exist and that different patterns and combinations are required for each activity

Assessing the Kinesiological Aptitude of the Performer Just as each activity has its own demands so each performer or each team has his or its own abilities and potentialities Kinesiology helps the coach and teacher to match the performer to the activity and the activity to the performer A short stocky boy would be much more apt to be a successful gymnast than he would be to achieve fame as a high jumper A basketball coach with a team of *predominantly* tall heavy slow moving men might select the zone as his defensive system although in theory he might prefer the man to man defense and would utilize it if he had personnel adapted to it

Preventing Athletic Injuries Although athletic injuries are usually associated

utilized effectively only by a skillful, artful practitioner who is the master of the basic subject matter In the following paragraphs, specific ways of applying kinesiological principles to the teaching of sports and games are presented

Describing the Movement to be Performed It is an axiom of educational psychology that a learner must have a clear knowledge of what he is trying to learn if orderly progress is to be made This is especially important in learning motor skills At the first attempt a hook pass or a high jump or a kip on the horizontal bar is likely to be a mysterious and frustrating complexity An important task of the teacher is to instruct the learner in exactly what to do

Kinesiology helps the coach to view performances analytically First, he must analyze expert performance (through the neuro muscular memory of his own past performance, or through observation of other experts or through the study of pictures and descriptions) so that he may demonstrate point out, or explain the desired performance to the learner Second, he must analyze the learner s performance so that he may call attention to the factors responsible for errors and successes and thus provide a basis for subsequent and more successful attempts by the learner

Descriptions of motor skills must take into account some or all of the following factors

1 The posture or position at the start and the finish
2 The direction of each action at each joint (Hip flexion, spine rotation to the right etc)
3 The kind of motion at each joint (Fixation, moving fixation, ballistic motion etc)
4 The sequence of joint actions
5 The speed and acceleration of joint actions
6 The force of joint actions
7 The source of motive power for each joint action (Concentric contraction eccentric contraction static contraction, or some external force such as gravity)
8 The timing coordination, and rhythm of joint actions
9 The integrated pattern of the joint actions
10 The muscular or skeletal or external stabilization necessary

It is not implied that all of these factors should or could be brought to the conscious attention of the learner, nor that technical language should be used in communicating the ideas In addition to the factors listed there may be other important factors such as clothing implements equipment and other external masses each with force speed, direction momentum and so forth Also there may be non kinesiological considerations, such as game strategy fear motivation and so forth

Analyzing the External Mechanics of the Performance External mechanics refers to the movements of the gross body segments and their externally applied leverages forces and other physical factors Since mechanics as a branch of classical physics is rather completely worked out and its validity firmly established a person with a knowledge of mechanics can make logical applications to sports performance with relatively great confidence Mechanical analysis thus becomes one of the most potent phases of applied kinesiology

Earlier chapters in this text have presented the fundamentals of mechanics

abandoning such precise systems physical education has probably tended to give too little attention to evaluating the effect and worth of each activity

A physical educator should constantly be asking What are the purposes of this activity and to what extent does the activity help to achieve these purposes? In most cases the answers require a broad knowledge of the biological sciences When they deal with physical development or motor skills, an understanding of kinesiological principles becomes essential

WARM UP

The coach will normally start a training session by having his athletes warm up believing that this is indispensable for maximum performance and aids in the prevention of injuries The evidence on the value of this procedure is confusing It has been asserted that warm up improved the performance of swimmers [4] but did not improve the performance of runners [5] that it did not improve strength speed or accuracy [6] that formal warm ups improved speed and endurance in swimming and accuracy in bowling and foul shooting but that informal warm ups did not improve strength,[7] that it improved strength but did not improve speed of movement, endurance, or accuracy [8] that it resulted in decreased times for performing both long and short bicycle rides at maximum effort and in improved dynamometric strength scores [9] The effect of warm up on the prevention of injuries may be even more important than its effect on performance but is, of course, extremely difficult to evaluate

Part of the confusion over the subject results from an ambiguous use of terminology Preliminary exercise may be local or total body general (formal) or specific (informal), of long or short duration and involving light or heavy resistances Some writers equate warm up with preliminary exercise others equate it with passive techniques such as hot showers and massage Clearly, some of the discrepancies between experimental results are caused by radical differences in the kind of warm up employed and by the test exercises used

Warm up benefits to performance have been demonstrated in a sufficient number of experiments to warrant the tentative conclusion that *preliminary exercise often improves subsequent maximal performance* The experiments suggest that benefits are associated with preliminary work which is relatively intense long and accompanied by increased deep muscle temperature However the experiments also suggest that the benefits of warm up when they have been detected at all are inclined to be smaller in magnitude than has generally been assumed by athletes coaches and physiologists

Laboratory studies have shown that cooling intact muscle increases the reaction time two or three times as much as the contraction time of the muscle [10] reduces the excitability of the muscle [11] increases the duration of the action potentials (indicating a decrease in the propagation velocity of the impulse over the muscle fiber) and decreases the amplitude of the action potential [12] Reduced muscle excitability reduced velocity of transmission and a failure of the antagonists to relax would lead the kinesiologist to anticipate both poor performance in explosive movements and a tendency for the performer to suffer certain types of injuries such as sprinter s strain Increases of 8 to 10 F in the skin temperature[13] and of 4° F in deep muscle temperatures[9] have been observed Diathermy and hot showers have also been found

with intense competitive activities at the interscholastic level they refer as well to minor abrasions and sore muscles which might occur in a hop scotch game in the elementary school Their prevention depends in part upon intimate knowledge of the somatic materials and arrangements of the human body of the quality and character of environmental objects and sports implements of the nature of forces and other potential hazards in various activities and of many other factors which constitute the subject matter of kinesiology

Making First-Aid Diagnosis and Deciding upon First-Aid Care In recent years medical and physical education personnel have come to closer agreement upon the professional division of their duties in the care of athletic injuries partly through more adequate professional training of physical educators and partly through an increased understanding of the nature and value of physical activities by physicians Only qualified medical personnel conduct diagnosis and treatment beyond the limits of first aid except when the consulting physician specifically prescribes exercises massage, or other treatment to be given by the trainer therapist, correctives teacher or others Although the extent of first aid care by the physical educator is limited he needs an understanding of the nature of trauma While he does not make diagnoses he must be alert to the possibility of involvements which are not immediately apparent in the symptoms displayed at the time of injury Kinesiological knowledge helps him to conduct first aid care until the victim can be brought to a physician for definite diagnosis and treatment When a doctor releases a patient from treatment he often imposes some temporary restriction upon the nature of subsequent activity He may for example indicate following an operation that the individual should engage in general exercise of moderate intensity but should avoid activities which might put excessive strain upon the abdominal wall Such a decision is the responsibility of the doctor alone but he frequently leaves it to the judgment of the physical educator or therapist to determine what comprises exercise of moderate intensity or what activities might strain the abdominal wall In either event an advanced knowledge of the nature of activities and the nature of the human body is essential if the physical educator or therapist is to be adequately qualified to undertake such responsibilities

Adjusting Equipment, Clothing, Apparatus, Implements, Grounds, and Other Factors Kinesiological knowledge determines to a great extent answers to such questions as the following How long a bat should a baseball player use and how much should he choke his grip on it? What is the optimal shape and length of football cleats for use on a turf of a certain quality? How close *to the basketball court boundaries at the side of the gym can the parallel bars* be safely stored? Are long trousers a hindrance to performance or a safety hazard for a boy engaged in tumbling? Is it safe to play soccer on a field which has small impressions left from the shot put practice of the day before?

Evaluating the Effect and Worth of Activities In the hey day of the Swedish System of Gymnastics it was argued that each movement should cause a definite and predetermined effect upon the physiology or development of the body and that exercise dosages could be prescribed accurately by specifying a certain number of counts or repetitions It is now known that such precision and pre determination of purpose is impossible In the historic process of

FIG 183—A typical situation in Olympic free style wrestling which illustrates the complexity of muscular action in this sport (Photograph courtesy of the Associated Students of the University of California)

prone wrestler to avoid being turned over and pinned or a submarining lineman in football) require an extremely low center of gravity A high center of gravity has two disadvantages—first, the body may be upset by a force of smaller magnitude and second, an upsetting force applied low may more easily undercut the supporting members of the body In judo the lowering of the center of gravity to obtain greater stability is recognized as a tacit admission of the superiority of the opponent in baseball a catcher awaiting an oncoming runner crouches low so that there will be less chance of his being knocked down

4 For a given stance stability is proportional to the mass or weight of the body A heavy object of the same size and shape is harder to upset than a lighter one Therefore body weight *per se* becomes a tremendously important factor in physical contact sports Superiority in skill quickness strength and other factors may modify this advantage to a greater or lesser extent

to increase deep muscle temperatures, whereas massage did not [9] Asmussen and Bøje[9] found that within limits both deep muscle temperatures and subsequent performance increased as either the duration of warming up or the intensity of warming up was increased

It is the empirical experience of coaches and athletes that warming up appears to result in a decrease in injuries and many localities now have laws requiring that high school football players be warmed up before being sent into a game Certainly the experiences of hundreds of years are not to be lightly discarded Until the matter has been definitely settled it might be suggested that specific warm ups be utilized rather than general ones, since the practice effect is in itself of value regardless of whether it is accompanied by physiological benefits

STARTING POSITIONS

Kinds of Positions The starting positions in sports may be classified into three kinds according to whether their purpose is (1) to provide stability and resistance to external forces (2) to allow an optimal application of muscular force or (3) to prepare generally for any one of several possible movements Since these three purposes require the application of radically different principles of body mechanics the athlete and the coach must give considerable attention to the determination of the requirements of the sport and to the analysis of the positions to be assumed by the athlete

Stable Positions A position will be stable and will best resist the onslaught of various external forces to the extent that the following conditions are fulfilled

1 An imaginary line dropped vertically from the center of gravity should fall well within the area of the base of support This area is defined by straight lines connecting the most peripheral points of the body parts contacting the supporting surface Thus in decreasing order of stability we find the effective area of the base of a wrestler in the referee s position on the mat is a four point rectangle that of a person performing a headstand is approximately a three point triangle with the head and each hand at its angle a handstand has a stance composed of two points on a single line smallest and least stable of all is the one point stance of the ballet dancer on the toes of one foot

2 Stability against a force from a given direction is proportional to the distance in that direction from the point at which the line of gravity falls to the edge of the base If the direction of the upsetting force could be known in advance the body position could be adjusted so that the distance from the point where the line of gravity falls to the edge of the base in the direction of the on coming force is maximal Thus if a wrestler knew in advance that he was to be pushed forward he could move his hips backwards and extend and brace his arms in a forward position In practice he does not know whether he will be pushed pulled lifted or turned In such ambiguous circumstances the strategy of stability is to keep the center of gravity approximately over the center of the base

3 If stability is the primary consideration the center of gravity should be kept as low as possible In most sports a semi crouch stance is assumed when stability is threatened This is usually a compromise between stability and mobility but a few sports situations (such as a purely defensive attempt of a

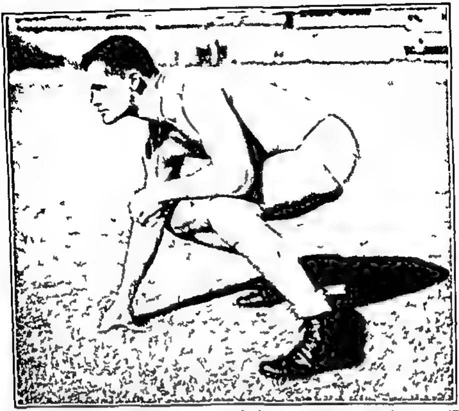

FIG 185 —Rod Franz All American guard demonstrates a typical stance (Photograph by Thomas McDonald)

FIG 186 —The charge The relative positions of the trunk and leg denote the application of maximum power The position of the arms is characteristic of line play (Photograph by Thomas McDonald)

Positions Designed For Optimal Force Production In the racing starts of the runner and swimmer in the waiting position of the baseball batter and in many other sports situations the starting position is adjusted primarily to enhance the application of muscular force on an external object The center of gravity tends to be at the edge of the area of the base opposite the edge next to which the force is to be exerted The baseball batter or pitcher (Fig

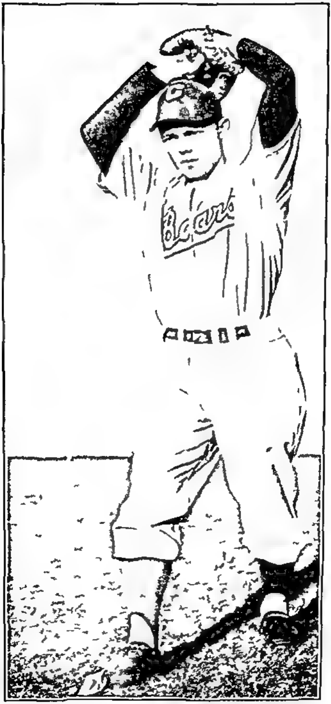

Fig 184 —Preparing to make the throw (Photograph courtesy of Associated Students of the University of California)

signal is given, contraction in the propulsive muscles intensifies and changes from static to concentric The antagonists are relaxed and reaction time is decreased because the propulsive muscles have already contracted sufficiently to take up any slack in themselves (Figs 185 and 186)

Relaxed starting positions are deleterious to performance In sports language, the relaxed performer is said to be caught flat footed ' This is the opposite of being on your toes (Fig 187) No doubt there are central 'alert

FIG 188 —The left jab Notice fixation of the scapula (Photograph by Thomas McDonald)

mechanisms as well as peripheral ones and there is evidence that these are located in the hypothalamus [14]

When the initial propulsive movement is complete the joints tend to form a straight line as evidenced in the position of a sprinter at the end of the leg drive the boxer as his left jab or straight right hits its mark (Figs 188 and 189) the swimmer as he leaves the starting platform and the shot putter as the shot leaves his hand The extending forces have reached their maxima at this terminal position of drive, and the extended joints are in the best position to bear the reactive weight of the drive If the joints were still

184) for example carries his weight to the rear so that he may step forward with sufficient momentum the sprinter carries his weight forward opposite the back edge of the base from whence he will be driving with his legs

In these positions the joints through which the driving muscles act tend to be held in an intermediate phase—that is, about halfway between flexion and extension Positions of extreme flexion or extreme extension would either reduce the mechanical advantage of the muscle bone levers by decreasing the angles of insertion of the tendons, or prevent effective movement because the

FIG 187 —A typical on guard position used by boxers (Photograph by Thomas McDonald)

shortening power would be all used up in attaining the extreme position In the sprinter s starting position 90 degree angles tend to predominate in the joints through which driving power will be exerted Actually it is not the angles of the joints but the angles of insertion of muscle tendons which must be arranged optimally

Ready positions or get set positions are not relaxed positions The muscles which will exert propulsive force are contracting statically while being held in check by co contraction in their antagonists When the go

making an offensive movement. Here the problem is not maintenance of stability, nor preparation to make a pre-determined application of force. Instead the problem is to be ready to move quickly in any direction with maximum speed. The center of gravity must be kept over the area of the base until the decision to move is made, but the area of the base is ordinarily reduced so that a small displacement of the center of gravity results in an unbalanced position. Usually the weight must be shifted from both feet to one foot, and if the feet are placed widely apart, the weight shift requires a longer time. Similarly, too low a center of gravity will slow the motion.

FIG. 190.—The ball carrier changing direction. Note the position of the right leg which is about to be planted to enable the runner to cut to his left. (Photograph courtesy of Associated Students of the University of California.)

The joints are held in positions intermediate between flexion and extension so that quick movement in any direction is possible, and because of factors described above.

It is evident that there is incompatibility between the positional requirements for stability and those for quick movement in any direction (Fig. 190). When the two purposes come into direct conflict the skilled performer adjusts his starting stance to effect a compromise. In sports which involve maneuvering between opponents, the stance of one player may provide information to his opponent regarding his intended actions at the "go" signal. The football guard must not take a stance when he is going to "pull out" and run interference which is different than he assumes when he is going to charge forward

in a position of flexion at this moment, the forces could not be borne efficiently

By the same token the body is best able to maintain loads when the joints are fully extended so that the pull of gravity is offset by the bones rather than by muscular contraction A weight lifter can ordinarily sustain the bar overhead if he can get his arms straightened, but will find it impossible to support the same weight aloft with his arms only partially straightened out In lifting the weight overhead, he keeps it as close to the body as possible in order to

FIG 189 —A straight right Power comes from ankle knee and hip extension body rotation and arm extension (Photograph by Thomas McDonald)

reduce the distance from the edge of his base to the point at which the line of gravity through the combined mass of his body and the weight falls Simultaneously he lowers the center of gravity by splitting or squatting thereby reducing the distance through which he must move the weight in order to get it to the chest or overhead

Positions of Readiness for Variable Movement Somewhat different from the foregoing is the *position of a baserunner taking a lead off from first base or a* defensive basketball player waiting for his opponent to declare himself" by

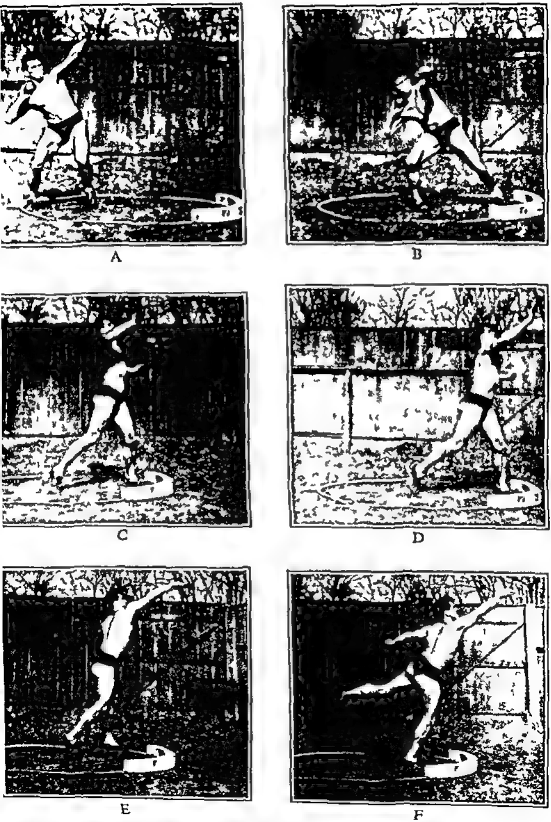

FIG 191 —The action of the whole body in putting the shot

even through adjustments in stance would be mechanically more efficient (Fig 185) Scouts closely observe the position of backfield players feet, since many players tend to turn one foot in the direction in which they are to run The resulting gain in mechanical efficiency is more than offset by the informa tion given to the opponents Therefore the football player, unlike the sprinter on his starting blocks is forced to assume virtually the same stance on every play and may face in a direction directly opposed to the one in which he is to run This versatile compromise stance must be very carefully planned and practiced if it is to serve the performer well in all of the various maneuvers he must execute in the course of a game

On the other hand a performer may use variations of stance in order to deliberately mislead the opponent He may also use movements of the eyes head shoulders or hands in order to feint the opponent out of position Ideally such a feint is obvious enough to mislead an opponent but subtle enough to avoid interfering with the movement which is actually contem plated Primarily this means that it must be strong enough to cause the op ponent to react to his disadvantage but must not be so strong that it displaces the feinter s center of gravity in an undesirable direction, and thereby places him at the disadvantage Every athlete and coach should study the kinesiology of effective feinting Observation of skilled performers in action is essential textbook descriptions cannot adequately describe feinting techniques in a practical manner, although many of the kinesiological principles mentioned above will be helpful

TERMINAL POSITIONS

Terminal positions may be categorized as follows

1 Those which are irrelevant to the performance The high jump and pole vault provide examples While the performer has a need to avoid injury, which is usually met by providing a deep bed of soft shavings the judges ignore terminal positions

2 Those which are arbitrarily specified and which reflect the quality of the preceding performance Instances are found in ski jumping diving and gymnastics as well as in events such as shot putting discus and javelin in which a restraining line must be observed (Fig 191) The gymnast is strongly judged on the steadiness of control of his landings and dismounts because the quality of the terminal position directly reflects the precision with which the body was controlled prior to the landing A half knee bend is employed in gymnastic landings not only to absorb impact force, but also to lower the center of gravity and thus increase stability (Fig 192) The arms may be extended outward to act as balancing poles

3 Those which are integrally related to the strategy or objective measure ment of the performance For example the broad jumper who lands and falls backward instead of forward reduces the measurement of his jump The tennis player who reaches to make a beautiful backhand shot but who then stumbles to the ground finds himself effectively penalized because he cannot return to center court in readiness for his opponent s return shot (Fig 193)

Sport skills often employ the terminal position or terminal movements of one movement to contribute to the execution of the next one The forward momentum of the tennis serve may be employed to carry the server forward

into a strategic position on the court. Properly done, bunting a baseball is an integral part of the start of the run toward first base. A long fly ball may be caught high on an outfielder's throwing side, so that the subsequent throw to the infield can be commenced without wasted movement.

STRENGTH

Muscular strength is perhaps the most important of all factors in athletic performance. One study[15] has indicated that in certain cases, at least, McCloy's General Strength Quotient gives the best index of ability to learn an unfamiliar or new activity. This may also apply to activities which are not commonly thought of as strength activated. The rationale for this statement is partly explained by a common physical formula expressing kinetic energy.

Most sports skills require the development of kinetic energy, which may be defined as $\frac{1}{2}mv^2$, in which m = the mass of the object and v = the velocity

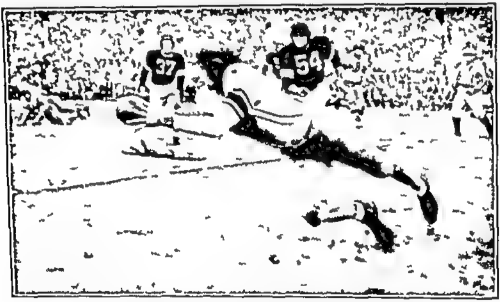

FIG. 193.—Pass reception. Illustrating the difficulties of applying precise technique in a real game situation. (Photograph courtesy of Associated Students of the University of California.)

of the object. The object may be the body itself, as in the case of running and jumping, or a projectile, as in the case of a baseball or javelin, or a sports implement, such as a baseball bat or tennis racket. The greater the kinetic energy developed, the faster will be the run, the further the throw, or the more powerful the striking of the ball. An elementary formula of physics states that $Fd = \frac{1}{2}mv^2$, in which F = force, d = the distance over which the force is applied, and $\frac{1}{2}mv^2$ = kinetic energy. The magnitude of kinetic energy, then, is directly proportional to both the force exerted and the distance over which it is applied. In sports, force is usually derived mostly or entirely from muscular strength.

In sports applications, the mass (m) in the kinetic energy formula is ordinarily constant. If we assume also that the distance (d) through which the force is applied is also constant, it follows that velocity increases with an

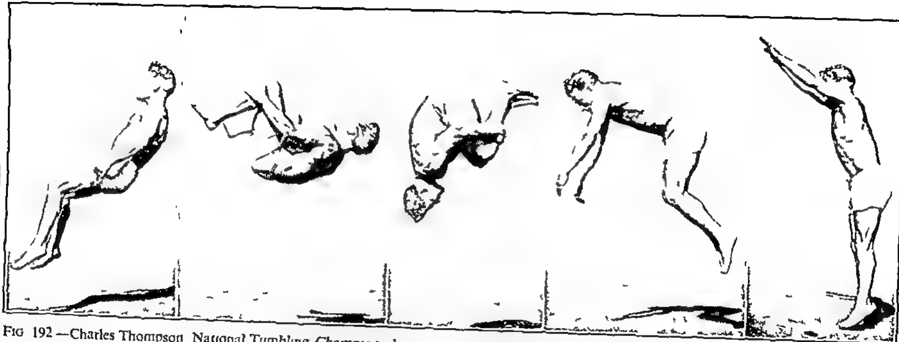

FIG 192—Charles Thompson National Tumbling Champion, demonstrates the forward somersault Notice the relatively great height reached at the top of the exercise (Photograph by Thomas McDonald)

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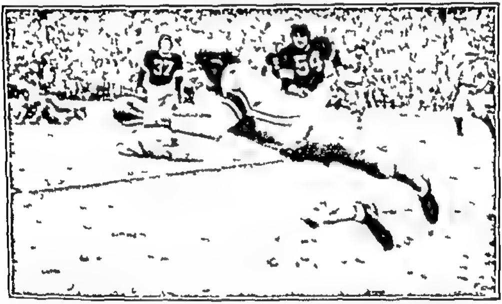

FIG 193—Pass reception Illustrating the difficulties of applying precise technique in a real game situation (Photograph courtesy of Associated Students of the University of California)

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increase in force In this situation however, $F = v^2$ or $v = \sqrt{F}$ For each fourfold increase in force there is only a doubling of velocity This relationship points out the fact that there is a diminishing return for progressive increase in muscular strength as follows

Force	*Velocity* ($=\sqrt{F}$)
1	1 0
2	1 4+
4	2 0
8	2 8+
16	4 0
32	5 7−
64	8 0
128	11 3+

Overload Principle The overload principle states that increases in muscular strength hypertrophy and endurance result from an increase in the intensity of the work performed in the given time unit[16] The work may be intensified by raising the cadence or by increasing the resistance against which the muscles contract Examples of the use of these devices may be found in *interval training* in track *in the use of progressive resistance exercises in the* gymnasium and elsewhere Whether the exercise is isotonic or isometric does not appear to be important If an individual desires to increase his muscular strength hypertrophy, and endurance he must be willing regularly to subject his body to the stress of repeated all out efforts In the case of a patient in a physical medicine and rehabilitation clinic this may be at a relatively low level of accomplishment on any absolute scale, but the important thing is that it represents a maximal volitional performance for the individual This is achieved only when the person concerned is motivated by some powerful *psychological drive The physiological mechanisms underlying these responses* have been discussed at length elsewhere[17 20] but it is clear that responses to physical activity are neuromuscular, not simply muscular The development of skill the more effective utilization of the central nervous system and the overcoming of psychological barriers are integral aspects of the overload principle

As a corollary to this principle the total amount of work done without any increase in the intensity thereof is without significance for the development of the kinesiological factors under consideration Once the body has become accustomed to and able to sustain the strain placed upon it by routine work it will not of its own volition make additional gains with a view to making the work easier to perform For this reason the average manual worker or housewife does not display the well developed body or physical ability of the athlete even though the demands of their particular occupations *may have developed certain abilities which the athlete might find* it difficult or impossible to equal until he or she had had an opportunity to become proficient in the worker s specialty

Athletes may attempt to intensify their training by practicing with a shot which is heavier than the one which they will put in competition running distances greater *than that of their event swinging three bats while awaiting* their turn at the plate or by similar means While procedures of this sort do

invoke the overload principle, they clash with the principle of specificity of training This again illustrates the need for professional training in kinesiology if the coach is to make wise use of its principles

The Principle of Rest Pauses When the exercise is heavy a greater amount of muscular work can be accomplished if it is interspersed with rest periods In general short frequent rest pauses seem to make for greater efficiency in muscular work than do long infrequent rests The physiological principles underlying rest pauses have been considered by Mueller[22] Weight trainers have found from experience that it is advisable to take a short pause between each set of exercises, the studies of Clarke Shay and Mathews[23] suggest that about 2 5 minutes comprises the optimal time There appear to be no data in the literature regarding the use of rest pauses in other forms of athletic training but from the practical standpoint it will be noted at track meets that the program is arranged in such a way as to provide a rest period between the

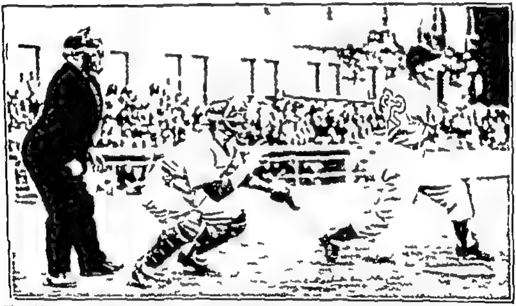


FIG 194 —A swing hitter connects with the ball Notice the follow through (Photograph courtesy of the Associated Students of the University of California)

100 yard dash and the 220 yard dash and between the half mile and the mile runs so that a competitor in either of these pairs may enter both of the events without too great a handicap being imposed upon him in the second one

FOLLOW THROUGH

The principle of follow through is an important element in all sports skills involving powerful propulsion of an object Such skills include stroking a tennis ball batting shot putting discus throwing javelin throwing punching (as in boxing) and blocking and tackling (as in football) In the popular mind follow through is often thought of as a continuation of motion after the contact with the propelled object has terminated (*Fig 194*) However it is obvious that after the contact has terminated no action of the body can have any effect upon the path of the propelled object The body English exhibited for example by a bowler as the ball rolls down the alley is a useless kind of

motion, except as it may satisfy some little understood psychological need of the performer

Follow through is more properly defined as a continuation of a propulsive force so as to increase the duration of its application on the propelled object as long as possible (Fig 195) Under this definition the importance of follow through can be explained by the physical law expressed by the formula

$$V = at$$

in which V is the final velocity of the propelled object a is the acceleration (assumed here to be constant) and t is the duration of application of the accelerating force For a given constant rate of acceleration the terminal velocity is directly proportional to the time of application The time factor applies only to the duration of a *propulsive* force (that is an accelerating force) A force which only follows along with the propelled object without acting upon it so as to increase its velocity, has no effect on the object (Fig 196)

As a technique in communicating with a performer, a teacher may choose to emphasize a continuation of motion after the contact period (Fig 197) but this exaggerated coaching advice does not accurately reflect the physical principles involved

STABILIZATION

Newton s Third Law of Motion states that for every action there is an equal and opposite reaction When a baseball pitcher throws a ball he applies force about equally to the ball and to the pitching rubber The earth because of its great mass is stable and does not move detectably The pitching rubber is stable because of its anchoring pins attaching it to the earth The pitcher s body moves forward by rotating at the ankle joint Muscles stabilize the knee hip and spine joints to a great extent The arm, forearm hand and baseball exhibit the greatest motion The propelling force is largely applied to the baseball because the other parts were effectively stabilized (Fig 198)

A jump pass in football or basketball is poorly stabilized (Fig 199) The product of the mass and velocity forward of the football is equal to the product of the mass and velocity backward of the passer s body Some of the energy generated by the muscles has been wasted in propelling the passer s body backward Thus the jump pass is inefficient mechanically and is a skill employed only as a compromise with non mechanical strategic aspects of the situation Performance is often improved by attention to proper stabilization of the joints through muscular contraction and of the body against external objects through the use of spikes cleats surfaces with a high coefficient of friction and equipment such as track starting blocks or a pitcher s rubber One of the advantages of the semicrouch stance employed in football wrestling boxing track and swimming starts is its efficiency in directing forces of reaction into the earth so as to secure adequate stabilization

SUMMATION OF FORCES

From a mechanical point of view the main problem in many elemental sports skills is that of creating maximal acceleration in an object or a body segment If a given time period is available for the application of force to an

A B C D E

Fig 195 —Fortune Gordien of San Francisco Olympic Club National Champion and holder of the World s record of 190 feet 7¼ inches demonstrates the initial position of the discus throw

A —The athlete s back is toward the direction of the throw *
B —The first turn two thirds of the way through completion
C —Position the thrower just before the left foot strikes the ground to reach the final throwing position The extraordinary amount of rotation of *the hips in advance of the shoulders is evident*
D —The final throwing position The body is starting to unwind The enormous amount of power obtained from extension of the right leg body rotation and arm swing is suggested by the illustration
E —The release The position of the arm indicates the relatively high angle of departure of the discus characteristic of championship form
*(Figure 195, photographs by Thomas McDonald)

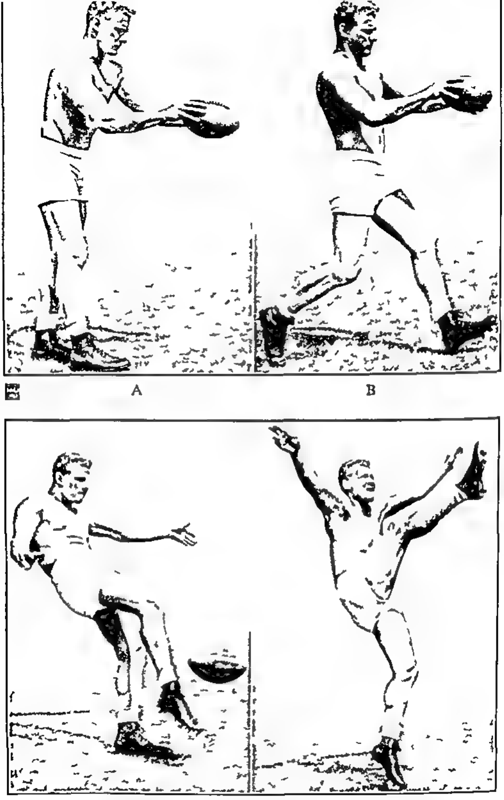
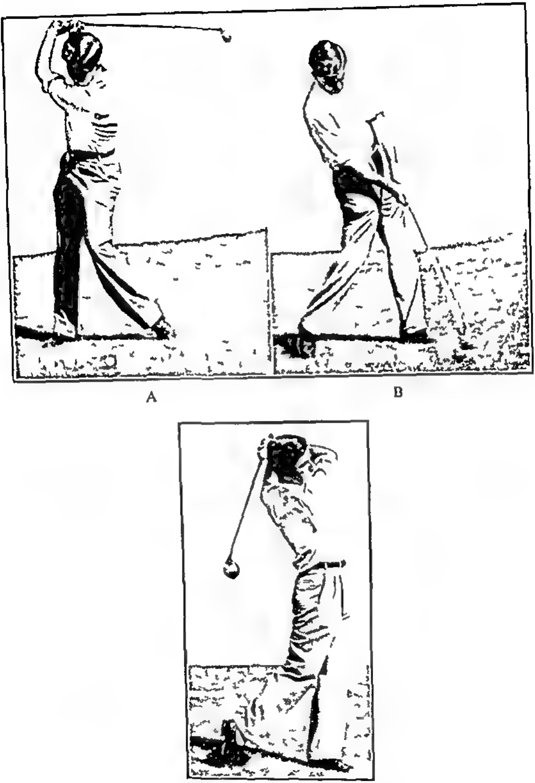


FIG 196 A —Jack Jensen All American backfield star demonstrates the stance used preparatory to punting

B —The first stride taken just before the ball is dropped The position of the ball remains unchanged

C —The foot coming forward to meet the ball The swinging leg will come into extension at the instant of impact

D —The follow through with the supporting foot off the ground (Photographs by Thomas McDonald)



A B

C

FIG 197 A — Sandy Munro demonstrates the backswing Notice the cocked wrists the horizontal position of the shaft and the position of the player s feet and legs

B —Position of the left arm and the club shortly after the impact with the ball

C —The follow through

* Photographs by Thomas McDonald

FIG 198 —The delivery (Photograph courtesy of the Associated Students of the University of California)

object its acceleration will be directly proportional to the amount of force applied ($F = ma$, where F is the average force applied, m is the mass of the object, and a is the resulting acceleration). The basic problem, therefore, is to recruit all forces available so that the total is maximal. A knowledge of the principle of summation of forces is helpful in analyzing such skills and in formulating coaching advice.

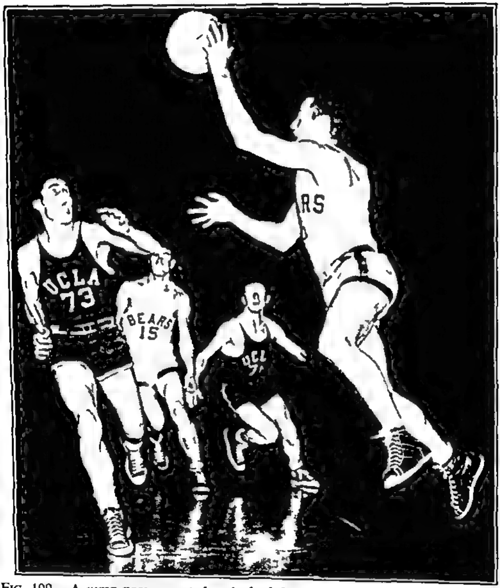


Fig. 199.—A jump pass executed with the left hand. (Photograph courtesy of the Associated Students of the University of California.)

Assuming that all of the forces come from the contraction of muscles, there are two fundamental ways in which the forces from different muscles may be summed: first, by simultaneous contraction, and second, by sequential contraction.

In a given action of a single joint, the various muscles which perform that

motion ordinarily contract simultaneously Sometimes, however one muscle by virtue of its position and structure, acts mainly in the first part of a joint action, while another muscle acts mainly in the latter part of the joint action Detailed knowledge of such facts may be important to the physician or the therapist in dealing with problems of surgery or rehabilitation, but the performer and the coach can safely ignore them since the sequence of contraction of individual muscles is controlled automatically and subconsciously in the

A B

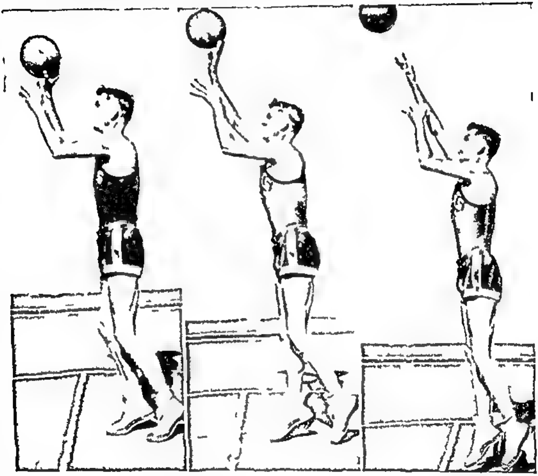
Fig 200 A —Jack Rocker demonstrates the chest shot Notice that the elbows are kept close in to favor arm extension
B —The release of the ball in the chest shot (Photographs by Thomas McDonald)

normal individual The performer therefore, should concentrate only on what movement to make and on making it with maximal force However the performer can often profit by making a deliberate attempt to adjust his body mechanics so that the muscular forces are applied to the object for the longest possible time (see for example the preceding section on Follow through)

Almost all sports skills involve combinations of actions in more than one joint and the muscular forces at each joint are added together and applied to the object For many reasons, some theoretical and some kinesiological or

practical it is ordinarily not possible or desirable to have all of these various forces act simultaneously Instead there is a definite sequence of joint actions and of the muscular forces powering them With proper timing and body mechanics the force of each subsequent joint action may be added, in effect to that of the preceding one This is somewhat analogous to the firing of a multi stage rocket and also in a way to the cracking of a whip

The shot put provides an example of summation of forces of various joint



A B C

FIG 201 A —The start of the one handed Western shot
B —The action of the wrist and fingers in the one handed Western shot
C —Completion of the one handed Western shot (Photographs by Thomas McDonald)

actions (Fig 191) Although there is some overlapping in the application of the joint actions they tend to take place sequentially starting with those most distant from the shot and ending with those nearest the shot The joints tend to be flexed at the beginning of the motion Various joint actions set the body in motion across the ring imparting an acceleration to the body as a whole Then a series of extensions and twistings occurs starting with the ankle then the knee the hip the trunk (rotation) the shoulder the elbow and finally the hand The force of each joint action accelerates all body parts above it

and the wrist and hand action applies a final force to the shot, which is already moving and has considerable velocity

For the summation of forces to be effective, there are two important conditions First, for each successive joint action to make its maximal contribution, the joints below it must be firmly stabilized so that no back sliding results from the reaction component of the force (Newton s Third Law) Thus each joint action tends to end with a static contraction phase Second the forces of each successive joint action must be precisely timed If any time intervenes between the application of the successive forces, the shot merely coasts along

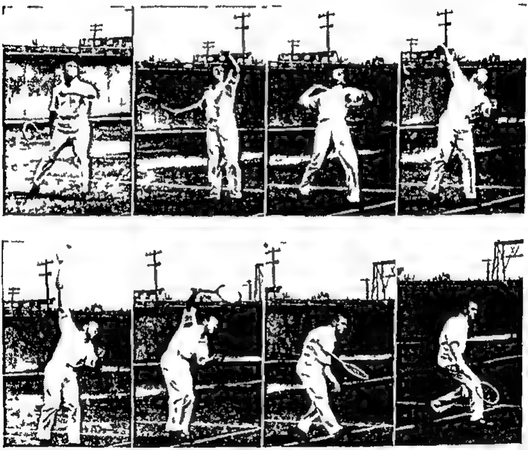


FIG 202 —Smash by Patterson (Courtesy of American Lawn Tennis, Inc From *Mechanics of the Game of Lawn Tennis* Vol II by J Parmly Paret)

at its existing velocity Better timing could have utilized this distance and time period for the imparting of additional force thus providing additional acceleration

The principle of summation of forces together with its elements of adequate stabilization and optimal timing can be observed in shooting a basket (Fig 200 and 201) executing a left jab serving a tennis ball (Fig 202) kicking a football driving a golf ball and many other skills In some activities the sequence of joint actions begins in the upper body and terminates at the ankle and foot Various jumping styles, execution of a back somersault in tumbling and performing the racing start in swimming are cases in point

CONSERVATION OF ANGULAR MOMENTUM

Angular momentum is the product of the moment of inertia* times the angular velocity This always remains constant unless the object is acted upon by an outside force (Newton's First Law) If one of the two components (for example, the moment of inertia) is decreased the other (angular velocity) must be correspondingly increased, and vice versa so that the product of the two factors remains unaltered Applications of the law of conservation of angular momentum appear frequently in sports activities being apparent whenever there is a spin pivot twist somersault, or pendulum swing involved in a sports skill The principle may be explained, non technically by describing two skills whose performance depends crucially upon its operation

A figure skater, with arms stretched out sideways swings into a series of spins or pirouettes while balanced on the point of one skate The angular momentum was achieved originally by pushing off with the other skate, and by swinging the arms in a horizontal circle against this resistance The original momentum continues to spin the skater, if he holds his outward reaching arm position until friction gradually decelerates him to the point of loss of balance However, if the arms are drawn in and folded on the chest during the spins the speed of rotation (angular velocity) is markedly increased so that the pirouetting skater appears as a blur to the spectator When the skater wishes to discontinue this rapid spinning he thrust his arms outward again, whereupon his angular velocity is greatly decreased

A diver performing a one and one half front somersault in tuck position gains his initial rotation by leaning forward on the take off from the board The speed of this original rotation is moderate, but as soon as the diver is in the air, he draws his arms and legs in toward the center of the body (tuck position) and the speed of his forward spin increases greatly After about one full somersault the diver emerges from the tuck position and extends his arms legs and trunk into layout position whereupon his angular velocity decreases markedly The diver seems to float slowly through his last half somersault before making his head first entry into the water The same principle holds when a gymnast executes a front somersault (Fig 192)

Conservation of angular momentum may be further explained by returning to the example of the spinning skater For simplicity, one arm only may be considered and the mass of that arm may be assumed to be accumulated at its center of gravity, just above the elbow The original momentum was sufficient to impart a certain angular velocity, and the center of gravity will traverse a certain circular distance at elbow's distance from the center of rotation in a given time period Now when the arm's center of gravity is drawn in toward the center of rotation, it follows a circular path of smaller radius and shorter circumference If the body continued to rotate at the same angular velocity the distance traversed by the arm's center of gravity would

* The moment of inertia is obtained by multiplying the mass of each particle of the body by the square of its perpendicular distance to the center of rotation and summing all such products for the whole body It may help the beginning student to think of the moment of inertia as an approximation of the average distance from the center of rotation at which the mass of the body is concentrated It approximates but is not identical with the center of gravity of the body

be much smaller in the given time period This, however is not possible under the law of conservation of angular momentum Instead the angular velocity is increased sufficiently so that the arm s center of gravity traverses in the given time period a distance equal to that which would have been traversed along the circle of greater circumference at the slower original angular velocity Momentum—which has here been expressed as a mass distance time relationship—has been conserved neglecting its dissipation by air resistance and friction between skate and ice A more complete and theoretically valid explanation can be found in any good elementary textbook of physics

The principle of angular momentum is so commonly involved in sports skills that a teacher who understands and can recognize it will be able to give effective coaching advice in many activities with which he has had little experience as a performer In gymnastics and diving the law has almost constant application Mechanically speaking the pole vault differs from the high jump largely in the fact that it involves the movement of a pendulum on a pendulum i e linear motion is converted to angular motion at the ground level, when the pole pivots within the box, and again at the other end of the pole, when the vaulter s body pivots around his hand grip At the take off the center of gravity is directly below the point of support The take off leg is flexed and then snapped down hard to implement Newton s Third Law (often giving rise to heel bruises) As the body leaves the ground the knees are flexed up toward the chest and the body rolled backward to conserve angular momentum The center of gravity pivots around the center of rotation (hand grip) and the leverage of the pole flings the vaulter into the air Once off the ground the vaulter keeps his center of gravity as close to the pole as possible since any weight at an angle to the pole will slow the movement of the pole"[14] (Fig 203)

As a football quarterback pivots to hand off the ball he decreases the radius of his pivot by pulling one leg his arms and the ball closer to his vertical axis of rotation thus increasing his speed A basketball or football player starting from a spread out position with a relatively large radius measured from his pivot foot can pivot or feint more rapidly if he draws his arms and free foot back toward a vertical axis of rotation over his pivot foot

The tumbler diver or trampoline man who performs a twisting somersault employs the principle of conservation of angular momentum around two different axes of rotation simultaneously First his somersault may involve some shortening of radius around the axis through his hips similar to that previously described for diving Second his twist which is a rotation around a head to toe axis involves an initial arm swing like that of the figure skater followed by a pulling in of the arms toward the chest which increases the speed of the twist At the termination of the twisting somersault both radii are lengthened again slowing both of the rotations so that a controlled landing or entry into the water may be achieved

A baseball pitcher starts his throw with an extended arm rotating around the shoulder axis with a large radius (Fig 198) As the arm is brought forward elbow and shoulder joint motions draw the ball closer to the shoulder effectively increasing the speed of the ball just before its release The football passer does not use this technique because (1) baseball pitching speeds which approach 100 miles per hour would be impractical in the football situation,

(2) he cannot afford the time nor risk the unbalanced position, and (3) the shape of the football and the choice of moving targets requires a sacrifice of speed in favor of accuracy (Fig 204)

FALLING

The dangers of falling result largely from impact, or the reception of forces therefore, some of the related kinesiological principles will also apply to the problem of receiving the impact of objects in sports such as occurs in catching a hard-driven ball The following discussion, however assumes for the most

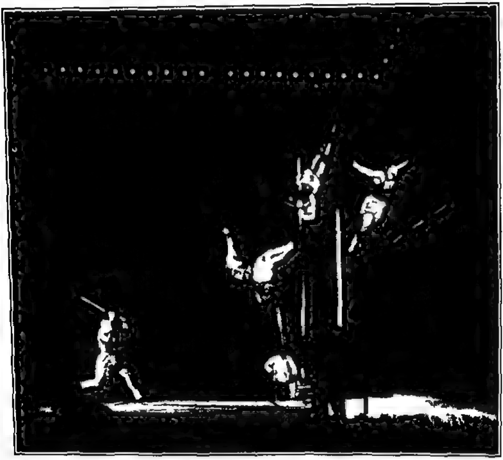


FIG 203 —Application of the Conservation of Angular Momentum in pole vaulting (Edgerton)

part that the body is falling under the influence of gravity The factors to be considered are (1) the velocity at the moment of impact (2) the mass of the falling body (3) the distance through which the deceleration takes place (4) the surface area through which the impact is absorbed (5) the part of the anatomy subjected to the impact and (6) the properties of the surface on which the body lands

The following formula expresses relationships which are helpful in understanding several of the problems of falling

$$\text{Work} = Fd = \tfrac{1}{2}mv^2 = \text{kinetic energy}$$

in which F is force d is the distance through which it is applied, m is the mass of the body or object, and v is the velocity of the body or object The problem is to do work so as to absorb the kinetic energy of the fall and to do this work safely

The kinetic energy of the fall is proportional to the square of the velocity Anything which can be done to reduce the velocity will pay off with geometrically accruing benefits Usually the velocity of the fall is the result of the acceleration of gravity This gravitational acceleration constantly in

FIG 204 —Jack Jensen getting off a pass The weight has just been shifted to the left leg as the ball is being brought forward (Photograph by Thomas McDonald)

creases during the fall and the speed increases geometrically The time of falling can be decreased if there is some warning A fainting person, for ex ample can sometimes start to sit or lie down before becoming completely unconscious at which time falling becomes free and uncontrolled A ladder or other tipping object starts to fall slowly and although it may be impossible for the person on it to recover balance there may be a moment in which he can climb slide or step down part way, and thus reduce the time and height

of the fall Sometimes grasping or contacting stationary objects on the way down may decrease the acceleration of the fall people have fallen amazing distances through tree limbs or through an awning without sustaining serious injury

The impact of landing is proportional to the mass of the falling body Heavy masses do not fall any faster, however, and it is sometimes wise to retain a grasp on an object For example falling onto a large pasteboard carton held in one s arms may be preferable to falling directly onto a floor But if the object in one s arms is heavy and will be on top at the moment of landing it would be better to push it aside Obese persons, because of their greater mass without equivalent agility or strength, are injured more seriously by falls

The longer the distance through which deceleration takes place, the less the danger of trauma The equation cited above demonstrates that the greater the distance through which force is applied the less the decelerating force will have to be since the product of the two must equal the kinetic energy of the fall In the same manner that a fast ball is caught with giving of the arms the arms or legs may sometimes be used as shock absorbers powered by the muscles When the limbs are so used, they should be nearly but not quite extended at the moment of contact Joints which are locked in complete extension must absorb the impact almost instantaneously with the shock absorbing distance element reduced to a minimum the magnitude of the force required is likely to tear ligaments and shatter bones Falling with the arm elevated over the shoulder may force the humerous out of the joint through the triangular opening formed by the muscles beneath the armpit [25] In such activities as football and trampolining performers are coached to avoid extending the arms in order to break falls Boxers are taught to 'roll with the punch in order to reduce the force of the impact

If the impact of a fall is spread over a large surface area the magnitude of the force at any one place on the body is reduced It is obvious that landing on both feet is safer than landing on one In some cases, landing flat on one s back is preferable to landing on the small surface areas of one to four hands and feet Circus acrobats falling from great heights are said to prefer to land flat on their backs rather than on their feet The standard break falls of the sport of judo represent effective devices for spreading the impact of falls over large arm and body areas The judoka is taught to land on the well padded side of the thigh if possible and to take up as much of the shock as he can with the hands and feet In many falls in which there is lateral as well as vertical momentum part of the fall may be taken on the feet and the rest absorbed by doing a forward sideward or backward roll The sideward roll is often known as the football roll because some coaches teach it during warm up periods as a method of avoiding contact on the point of the shoulder after being tripped blocked or tackled

The deformability and compressibility of the landing surface makes a tremendous difference in the seriousness of falls People who fall out of hotel windows are sometimes uninjured if they land on the roof of a parked car which is surprisingly deformable and which increases the distance element in the work of absorbing the kinetic energy Asphalt or black top is noticeably

safer than cement as a landing surface and may compare favorably with sand or compressed earth Heavy turf, especially if the underlying earth is moist is markedly superior to dry compacted bare earth

The seriousness of trauma resulting from a blow depends largely upon the part of the anatomy receiving the impact Damage to the head is probably most to be avoided vertical and whip lash forces on the spinal column especially the upper parts, are probably next in seriousness Injuries to the viscera are fairly common, but this area does possess certain means of self protection The sight of an approaching blow results in a reflex contraction of the abdominal muscles When the blow is received the intestines tend to slide out of the line of force Most of the internal organs have a certain amount of mobility and are able to swing aside when their area is struck The vertebral column against which they might be crushed arches backwards to reduce the impact and is itself cushioned by the hydraulic buffer action of the aorta and inferior vena cava [26]

ACTION OF MECHANICAL FORCES ON MISSLES

Curves If a ball is thrown with a spin or hit off center so that it spins aerodynamic effects may cause it to curve in its flight The degree of curving will be positively related to three factors—the speed of the spin the weight of the ball and the roughness of its surface The direction of the spin determines the direction in which the ball tends to curve

An adequate mechanical analysis of curving requires reference to the complex workings of Bernoulli s principle a topic in aerodynamics The following is a more casual explanation as the ball rotates the roughness of its surface creates a greater air resistance on the side of the ball which is turning toward its path through space and a lesser air resistance on the side turning away from its path in space This difference results in a force acting on the ball at right angles to its main direction and the resulting lateral displacement produces the curved path (Fig 205)

Gravity tends to produce a parabolic downward curve in the path of the ball Thus in throwing a down curve (drop) gravity accentuates the curve in throwing a pure side curve (in shoot or out shoot) gravity has no effect on the extent of lateral curving and in throwing an up curve (up shoot or hop) gravity tends to counteract the extent of curving and vice versa As a result a drop is the easiest curve to throw, and an up shoot is most difficult

A tennis ball because of its light weight and fuzzy surface (if the ball is new) and a golf ball because of its dimples curve much more readily than a base ball

Rebound Angles When a beam of light is reflected from a surface its angle of incidence with the surface will be equal to its angle of reflection from the surface Rebounding balls tend to react in much the same manner although the relationship is subject to several discrepancies Rotation of the ball the area of contact the degree of penetration of the ball into the surface or of the surface into the ball all cause the angle of rebound to differ from the angle of incidence Roughly however we may assume that the angles of incidence and rebound are equal if the ball is not spinning and if both the ball and the surface are hard If the ball is spinning when it hits the surface the angle of rebound is markedly affected by the amount and direction of the spin Figure

206 illustrates the effect of back and top spin on the rebound of a tennis ball A cut or side spin will cause it to break to one side when it rebounds from the court

Gyroscopic Action The spin of an object in flight produces a stabilization against end over end tumbling and other erratic behavior This is called gyroscopic action The laws of gyroscopic action cannot be explained here but it may be said that the result is beneficial to the flight path of such sports

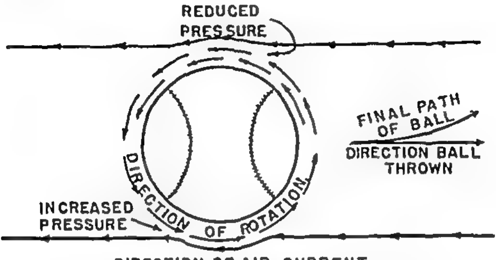


FIG 205 —Bernoulli s principle operates to deflect a spinning ball from its straight path By dragging a little air along on its surface as it spins differences of pressure are created on opposite sides of the ball

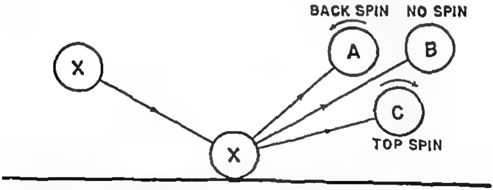


FIG 206 —Illustrating the effect of spin on the angle of rebound of a ball striking a horizontal plane surface Back spin increases the angle of rebound of *A* When no spin is present as in *B* there is no change in the angle of rebound it being equal to the angle of impact Top spin decreases the angle of rebound of *C*

implements as a football or a discus The effect of gyroscopic action Bernoulli s principle and other aerodynamic factors upon the flight of the javelin have been studied by Ganslen [27]

Air Resistance Small heavy smooth objects traveling at moderate speeds are affected very little by air resistance Large light irregular objects traveling at fast speeds may be deterred significantly in their flight path by air resistance

safer than cement as a landing surface and may compare favorably with sand or compressed earth Heavy turf, especially if the underlying earth is moist is markedly superior to dry compacted bare earth

The seriousness of trauma resulting from a blow depends largely upon the part of the anatomy receiving the impact Damage to the head is probably most to be avoided vertical and whip lash forces on the spinal column especially the upper parts, are probably next in seriousness Injuries to the viscera are fairly common, but this area does possess certain means of self protection The sight of an approaching blow results in a reflex contraction of the abdominal muscles When the blow is received, the intestines tend to slide out of the line of force Most of the internal organs have a certain amount of mobility and are able to swing aside when their area is struck The vertebral column against which they might be crushed arches backwards to reduce the impact and is itself cushioned by the hydraulic buffer action of the aorta and inferior vena cava [26]

ACTION OF MECHANICAL FORCES ON MISSLES

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Thus, a baseball or shot is seldom affected whereas a badminton bird or ping pong ball reacts obviously to air resistance

The object s speed referred to above, means its speed with respect to the airstream Wind resistance has the same effect as increasing the object s speed or in the case of a tailwind as decreasing the object's speed The surface area of the human body is not great enough to cause great retardation due to air resistance at ordinary speeds of self propulsion on a still day Hill[28] calculated that in running air resistance may be computed by the formula $R = 0\ 00107\ v^2 Ar$, where v equals speed in feet per second Ar equals projected area in the running position (approximately 0 15 times the square of the runner s height) By this formula R equals 32 horsepower for a typical runner, which is considerably larger than the estimates made by Elftman (0 15 h p)[29] and by Cureton (195 h p)[30]

In the event of a strong head wind, the relative speed of the body with respect to the airstream becomes large enough to cause significant retardation Strong winds also affect the path of small objects such as a baseball or foot ball Records made in track and field events are disallowed if the runner is aided by a tailwind of greater than a stated magnitude

Center of Percussion Tennis and baseball players know from experience that if a ball is hit at a certain spot on a racket or bat no vibrations are transferred to the hands and arms of the player In sports terminology this area is known as the sweet spot in physics it is known as the center of percussion or center of oscillation of a compound pendulum

If a ball hits a racket or bat at other than the center of percussion the resulting vibrations in the implement are unpleasant and some of the energy of the swing is inefficiently dissipated in setting up the vibrations

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FIG 207 —Incorrect technique of lifting Note that in this position the principal stresses will come on the muscles of the spinal column which, in this position is literally hanging from its ligaments (Photo by Pierson)

FIG 208 —Proper technique of lifting Note that in this position the principal stresses will come on the quadriceps femoris the largest and strongest muscles in the body (Photo by Pierson)

Chapter 21

Kinesiology in Daily Living

Lifting Since the levers of the human body are adapted for range speed, and precision of movement, rather than for weight handling it is not surprising that the incidence of back injuries attributed to lifting is extremely high Such traumata may be due to acute injury, such as is sustained by the industrial worker or to a continual mild overstretching of the muscles and ligaments such as is experienced by the housewife They may result from the nutcracker effect of compression forces or from lesions of the soft tissues These conditions are especially apt to occur in the elderly whose intervertebral discs and muscles have lost their strength and elasticity

To offset the mechanical disadvantages inherent in the human machine requires the use of the most efficient techniques of body mechanics Davis[1] has pointed out that general rules are difficult to apply, since the way in which burdens are lifted depends upon their size, shape position in space and the habits of the person lifting them He estimates that the theoretical maximum lift in the erect position is about 500 pounds, and notes that this figure is achieved by weight lifters A study[2] of the methods employed by them to raise these enormous poundages revealed that six cardinal principles were observed

1 The feet are kept flat on the floor The lifter does not balance himself on his toes as is sometimes shown in shop posters depicting the techniques of lifting

2 The legs are spread a comfortable distance (about 12 inches) apart to increase the stability of the body If the stance is exceptionally wide the muscles of the groin are more easily strained

3 The weight is kept as close to the lifter as is convenient

4 The spine is kept as straight as possible

5 The actual lifting is done by the largest and strongest muscles which can be utilized for the purpose—usually the extensors of the knees In most cases the knees are bent the object grasped in the hands, and then lifted by forcefully contracting the extensors of the knee and straightening the legs not by pulling upward with the arms and back

space to gain a reduction of momentum The inability to make this sacrifice and the dangers attendant upon loss of stability make lifting an object over head while standing on a kitchen stool or similar support a potentially hazard ous occupation In all overhead lifting an effort should be made to avoid thrusting the hips forward or increasing the lordotic curve of the back

Carrying Weights If the weight must be carried the problem is largely one of limiting insofar as possible the amount of displacement of the body neces sary to bring the center of gravity over the feet The most common cause of accidents in carrying loads is loss of balance resulting in insupportable muscular strains being placed on the body Observation of the following principles will assist in carrying loads in a safe and efficient manner

1 If possible the load is divided into two equal parcels and one is carried in each hand, so that the spine is kept straight

2 If the load is a single bundle the free arm may be raised sideward to assist in keeping the spine erect

3 The weight is carried close to the body

4 The most efficient handle to use on a bundle is the one which exerts the least concentrated pressure on the hands Carrying pails for example is less fatiguing if the wire bale is covered with a handle

5 When carrying packages in the hands the elbows are kept slightly bent to take some of the strain off the elbow joint When a worker must carry sacks the weight of the sacks should not exceed 60 kg on the level and 50 kg up stairs [5]

Bedale[6] measured the oxygen consumption per minute in various methods of carrying to determine the energy expenditure each required As sum marized in Table 18 it will be noted that the order of efficiency differs some what for different carrying methods

TABLE 18 —Oxygen Consumption in cc Per Min In Various Methods of Carrying

Weight in Pounds	*20*	*30*	*40*	*50*	*60*
	Oxygen Consumption Per Minute				
Methods of Carrying					
1 Tray carried in front of the body	464	522	613	675	
2 Tray carried in front strap around shoulders	473	522	604	656	
3 Weight carried in equal bundles in each hand	455	492	534	667	
4 Weight distributed on board on left shoulder	428	547	609	608	778
5 Tray on left hip	574	657	694	725	
6 Rucksack on back	561	573	608	700	
7 Weight in two pails supported by shoulder yoke	400	440	486	516	531
8 Tray on head	527	575	626	692	

Sitting and Rising In Western cultures it is tacitly assumed that an individ ual accepting an invitation to be seated will sit on a chair or davenport but

6 The lifter faces in the direction in which he intends to move, so that he does not have to turn while holding the weight and thus set up centrifugal forces which may result in injury In many cases however advantage may be taken of the counterbalancing of the body and follow through to perform in one smooth motion what might otherwise be accomplished in a series of inefficient discrete movements

) Upon careful analysis it will be found that almost all forms of work are performed most efficiently when these principles are kept in mind In using the wringer on a mop bucket for example, the cleaning woman will profit by facing in the direction in which the wringer handle moves so that the weight of her body may be applied on the down stroke and the strength of her legs employed on the up stroke At the other extreme, one acute witness[3] of the hard rock drilling contests of the early Southwestern miners has noted that the man swinging the hammer bent forward at the hip and knee as much as at the elbow and shoulder, caught the elbow of the lower arm on the forward thigh, and threw it back up into the air by the upward jerk of the leg The two types of work are very different, but the principles involved are exactly the same

Moving Weights When possible, heavy objects should be pushed rather than pulled and slid rather than carried In theory the force required to lift *a weight is approximately 32 times that required to slide it although in actual* practice this difference is reduced by the amount of energy necessary to overcome the friction involved [4] The principles for the most efficient method of pushing are very similar to those for lifting

1 The feet are placed a comfortable distance apart with one foot near to the object to be pushed and the other extended to the rear

2 The spine is kept straight and the hips are kept low

3 The hands are placed at the level of the object s center of weight If they are placed above it the object will tend to tip forward rather than to slide forward

4 The object is moved by contracting the extensors of the hip knee and ankle and straightening the legs not by extending the arms

Variations on the utilization of the principle of pushing may be found in the use of the shovel in which the advanced hand or hand and thigh may be used as a fulcrum and the weight lifted by pushing down on the shovel and in canoeing in which the principal effort is made by a push of the arm whose hand and fingers grasp the top of the paddle It should be noted that in both cases first class leverage is involved and force is gained by the fact that the force arm is longer than the resistance arm

Handling an Object Overhead The problem of handling an object overhead as in removing a box from a closet shelf, is rendered more severe by the fact that the moving of the object builds up a horizontal momentum and its position raises the center of gravity of the mover thus decreasing his stability and rendering him more likely to be tipped in the direction in which the object is moving or to suffer a strain in trying to prevent undesired movement A solution is to place one foot in advance of the other The object is first moved with the body s center of gravity supported by the advanced foot As the object comes forward, the body weight is shifted to the support of the back foot which can be moved still further backward if necessary In effect this sacrifices

restricted to athletes who have traditionally included squats, duck walks and similar exercises in their training programs Some years ago Kranz[10] advanced the theory that the practice of exercise of this type stretched the ligaments of the knee joint and predisposed the joint to injury It has been suggested that in a deep squat the thigh acts as a first class lever, with the fulcrum on the bulky triceps surae, and literally pries the joint open, thereby over stretching and weakening the ligaments As a result of such arguments use of these exercises has fallen into disrepute

Kneeling Certain types of work such as that of charwomen require frequent and prolonged kneeling In the opinion of some surgeons this may result in a wearing thin of the quadriceps fibers with a resultant tendency to rupture [11]

Stair Climbing Stair climbing is a special case of locomotion and an extremely fatiguing one It has been estimated that a person expends the same amount of energy in climbing one average flight of stairs that he does in walking on the level fifteen times the distance represented by the vertical height of such a stair case [12]

Placing the ball of the foot on the tread of the stair and then lifting the body by contraction of the gastrocnemius (plantar flexion) is considerably more fatiguing than is placing the entire sole of the foot on the tread and raising the body by extension of the knee joint By keeping the center of gravity forward the effect of the resistance arm of the thigh lever is reduced and energy is conserved The most efficient rate of stair climbing has been determined to be about 1 3 seconds per step [13] Elderly people may be observed to grasp the hand rail for support and to lean well forward The increased flexion of the hip thus obtained enables them to employ the gluteus maximus to better advantage in extending the hip joint

When descending a stair the body is kept more erect in order to prevent the center of gravity from getting too far forward The hip of the swinging leg is slightly flexed the amount depending upon the width of the tread, and the knee and ankle are extended The extensors of the hip, knee and ankle of the supporting leg gradually reduce the force which they are exerting and permit a slow flexion This is a typical lengthening contraction or negative work where gravity does work and the extensors resist it The body is lowered until the ball of the foot of the swinging leg makes contact with the step The weight is then transferred to this leg the knee of the other leg is flexed the foot lifted and swung forward and when the knee is extended the cycle is repeated Descending stairs requires about one third the energy expenditure of ascending them [12]

In walking down hill the quadriceps femoris must contract to keep the knee joint extended against the gravitational forces working on the body This continued stress is one of the reasons for the ache often experienced in that muscle after hiking

Sex Factors Where possible duties involving heavy lifting should be done by male workers since the strength of women as measured by dynamometer tests is about half of that of men The fact that women s thighs incline in toward the knees makes it more difficult for them to maintain their balance hence work which requires standing on a stool or at the top of a ladder is more safely assigned to men The inward inclination of the female arm accounts for women s difficulty in handling screwdrivers and other equipment

this is not necessarily true elsewhere One survey[7] found that sitting on the floor with the legs stretched straight ahead or crossed at the ankles or knees is a characteristic feminine seated posture in many other parts of the world, perhaps because it enables the woman to nurse a baby and at the same time carry on the weaving basket making and other tasks which usually engage her attention Sitting on the heels with the knees resting on the floor and sitting with legs folded to one side are also common postures among women in other societies Body position reflects anatomical, psychological, cultural kinesiological, and environmental factors The relative advantages and dis advantages of different positions in general use in various parts of the world have never been studied and offer the kinesiologist a fascinating field of exploration

In sitting down and rising one is confronted with the problem of supporting the body while the center of gravity moves backward and downward or for ward and upward as the case may be In sitting down on a chair the individual stands with his back to the chair places one foot slightly to the rear inclines the body forward from the hips to keep the center of gravity over the base of support, and lowers the body by relaxing the knee extensors and permitting the joint to bend In arising from a chair one foot is placed slightly under the chair, the individual bends forward from the hips and rises by contracting the knee extensors transferring the center of gravity forward so that it is supported by the forward foot

In sitting on or arising from a straight backed chair, the aid of the hands is not normally required In some deep chairs the center of gravity is thrown so far backward that it is difficult to sit down or rise and in such cases the arms are often used to assist in the movement Schools for fashion models and actors usually teach that it is ungraceful to employ the arms in rising

Older persons may find it difficult to sit in comfort or to arise after being seated for long periods Keegan[8] explains that poorly designed chairs cause an excessive decrease in the pull of the thigh trunk muscles This permits the lumbar curve to flatten and the hydraulic pressure resulting from anterior wedging within the fourth or fifth intervertebral disc may force a degenerated piece to protrude causing a painful stretching of the sensitive posterior longi tudinal ligament of the disc

When the vasti are paralyzed or weakened the weight of the body may be too great to be withstood by the knee extensors and the individual may be able to stabilize his body in the erect position only by hyperextending the knees so as to throw the center of gravity forward of the normal line of body weight A person so afflicted may sometimes be seen to place his hands on his knees and assist himself to rise by pushing the knees backwards as he leans forward

When the seated individual is required to operate foot pedals of some kind the thrust which can be exerted by the legs may be a matter of some impor tance The thrust exerted by the legs is at a maximum when the knees are bent at an angle of approximately 165 degrees At this point the mean thrust is about 227 kg If the knees are bent at a smaller angle there is a tendency for the upper part of the body to be pushed backward if they are bent at a greater angle there is a tendency for the body to be tilted forward [9]

Squatting Squatting is the normal resting position in large areas of the world In the Western culture it is considered undignified and its use is largely

He makes the important point that apparently easy work may be strenuous if it is done by relatively weak muscles, is of a predominantly static character, is performed in an awkward position, or is carried out under extreme environmental conditions

If left to himself the worker will take voluntary rest pauses, perhaps as an unconscious means of self protection The frequency and duration of these will vary with the severity of the work being done but for manual labor appears to approximate ten minutes out of every hour[21] It is not clear whether the figures optimal for men are necessarily so for women Mead[22] has pointed out that women seem to possess a capacity for continuous monotonous work, whereas men are characterized by sudden spurts of energy followed by a period of recuperation These differences appear related to the endocrinological systems of the two sexes, whether they have significance for kinesiology is yet to be determined

Rhythm Rhythm may be an important factor affecting the efficiency with which movements are made Each individual has his own preferred speed of movement It has been suggested that this is determined by the sum of all kinesiological physiological, and psychological factors involved and that the individual instinctively tends to move at the rate most efficient for his particular make up The ease and efficiency of movement may be increased if it is done to a distinct rhythm Wrappers of soap for instance have been observed to rhythmically sway their trunks and rotate their heads while at work The greater the amount of this movement, the greater was the efficiency of the worker[25] Perhaps one of the factors making for success in a famous backfield such as the Four Horsemen of Notre Dame or a dancing group is the combination of individuals whose preferred movement speed is identical On the other hand, an assembly line worker whose preferred speed of movement clashes with that imposed upon him by his work may find that he is subjected to stresses which render him both inefficient and unhappy

Additional Reading Articles and books dealing with what has been appropriately termed 'The Anatomy of Work[24] and Body Dynamics[25] are numerous The student of kinesiology will find that this study will enrich his life by giving new insights into his daily experiences and may lead him to new discoveries in a field in which scientific investigation has only begun

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requiring a rotary motion [14] In work requiring dexterity rather than strength however women are equal or superior to men

Working Space Arrangements Regardless of sex no worker can hope to function efficiently unless the arrangement of the equipment which he is required to use has been designed with a full consideration of anatomical and kinesiological principles Each job has its own peculiarities and may involve such details as determining the optimal load for a miner s shovel or the optimal length of a tuna fisherman s pole Here only the barest and most general outline can be given

1 Work benches and tables should be at the elbow height of the user whether he is sitting or standing

2 The height of work chairs should be adjustable They are in proper position when the operator s feet rest on the floor or on a support For the average male American the distance from the floor to the top of the chair seat should be about 18 inches

3 Levers to which maximum force must be applied should be at shoulder level for standing operators at elbow level for seated operators

4 Controls which must be used often should be between elbow and shoulder height

5 Convenient arm reach is about 28 inches controls more distant will probably require the average operator to bend his body

6 *For a side to side movement the strength of pushing is greater than that* of pulling in forward and back movements pulling strength is greater than pushing strength

7 Horizontal movements of the hand are faster than are vertical movements

8 Flexion movements of the arm are slower than extension movements [15,16]

Rest Pauses When Taylor[17] made his classical study of the application of kinesiological principles to the carrying of billets of pig iron, he nearly quadrupled work output by the utilization of three basic techniques (1) motivation (promising the worker an increased wage) (2) selection of the physical type best suited to the work, and (3) the introduction of rest pauses The question of rest pauses has received insufficient attention from the kinesiologists Unlike its mechanical counterparts the human machine cannot work continuously without a decided loss in efficiency During World War I the British found that the weekly output for a 55½ hour week was 13 per cent greater than that for a 74½ hour week During World War II American students determined that hours beyond 48 to 50 a week resulted in higher absenteeism higher injury rates and lower output per man hour [18]

Numerous studies of the energy costs of various industrial sports and domestic activities have been made [19] The energy output required is generally expressed in terms of calories used per minute and Christiansen[20] has suggested the following figures as standards for work classification

Light	2 5 – 4 9 cal/min
Moderate Heavy	5 0 – 7 4
Heavy	7 5 – 9 9
Very Heavy	10 0 – 12 4
Unduly Heavy	12 5 – Up

He makes the important point that apparently easy work may be strenuous if it is done by relatively weak muscles, is of a predominantly static character is performed in an awkward position or is carried out under extreme environmental conditions

If left to himself the worker will take voluntary rest pauses, perhaps as an unconscious means of self protection The frequency and duration of these will vary with the severity of the work being done, but for manual labor appears to approximate ten minutes out of every hour[21] It is not clear whether the figures optimal for men are necessarily so for women Mead[22] has pointed out that women seem to possess a capacity for continuous monotonous work, whereas men are characterized by sudden spurts of energy, followed by a period of recuperation These differences appear related to the endocrinological systems of the two sexes, whether they have significance for kinesiology is yet to be determined

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6 Medical Research Council *Sixth Annual Report of the Industrial Fatigue Research Board* London His Majesty s Stationery Office 1928 p 19

requiring a rotary motion [14] In work requiring dexterity rather than strength however women are equal or superior to men

Working Space Arrangements Regardless of sex, no worker can hope to function efficiently unless the arrangement of the equipment which he is required to use has been designed with a full consideration of anatomical and kinesiological principles Each job has its own peculiarities and may involve such details as determining the optimal load for a miner s shovel or the optimal length of a tuna fisherman's pole Here only the barest and most general outline can be given

1 Work benches and tables should be at the elbow height of the user, whether he is sitting or standing

2 The height of work chairs should be adjustable They are in proper position when the operator s feet rest on the floor or on a support For the average male American the distance from the floor to the top of the chair seat should be about 18 inches

3 Levers to which maximum force must be applied should be at shoulder level for standing operators, at elbow level for seated operators

4 Controls which must be used often should be between elbow and shoulder height

5 Convenient arm reach is about 28 inches controls more distant will probably require the average operator to bend his body

6 For a side to side movement, the strength of pushing is greater than that of pulling in forward and back movements pulling strength is greater than pushing strength

7 Horizontal movements of the hand are faster than are vertical movements

8 Flexion movements of the arm are slower than extension movements [15 16]

Rest Pauses When Taylor[17] made his classical study of the application of kinesiological principles to the carrying of billets of pig iron he nearly quadrupled work output by the utilization of three basic techniques (1) motivation (promising the worker an increased wage) (2) selection of the physical type best suited to the work, and (3) the introduction of rest pauses The question of rest pauses has received insufficient attention from the kinesiologists Unlike its mechanical counterparts, the human machine cannot work continuously without a decided loss in efficiency During World War I the British found that the weekly output for a 55½ hour week was 13 per cent greater than that for a 74½ hour week During World War II American students determined that hours beyond 48 to 50 a week resulted in higher absenteeism higher injury rates and lower output per man hour [18]

Numerous studies of the energy costs of various industrial sports and domestic activities have been made [19] The energy output required is generally expressed in terms of calories used per minute and Christiansen[20] has suggested the following figures as standards for work classification

Light	2 5 – 4 9 cal/min
Moderate Heavy	5 0 – 7 4
Heavy	7 5 – 9 9
Very Heavy	10 0 – 12 4
Unduly Heavy	12 5 – Up

APPENDIX

AREAS OF MUSCULAR ATTACHMENT

Figures 209-226, all of which are taken from *Gray's Anatomy*, the bony origins of the muscles are shown in red and the insertions in blue. The lines of attachment of articular capsules are indicated by a heavy blue line.

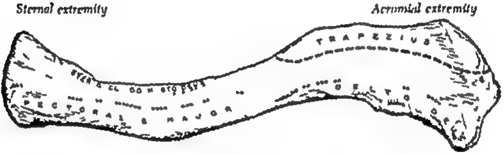

FIG. 209.—Left clavicle. Superior surface.

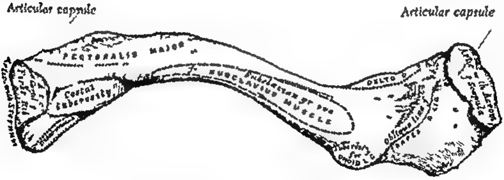

FIG. 210.—Left clavicle. Inferior surface.

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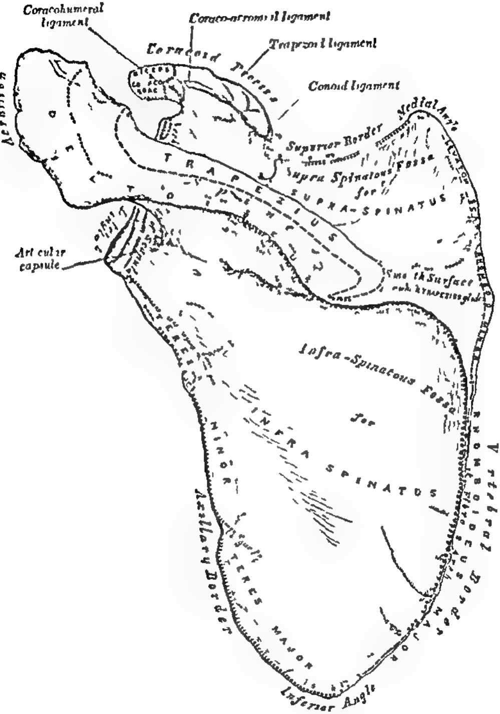


Fig. 212 —Left scapula Dorsal surface

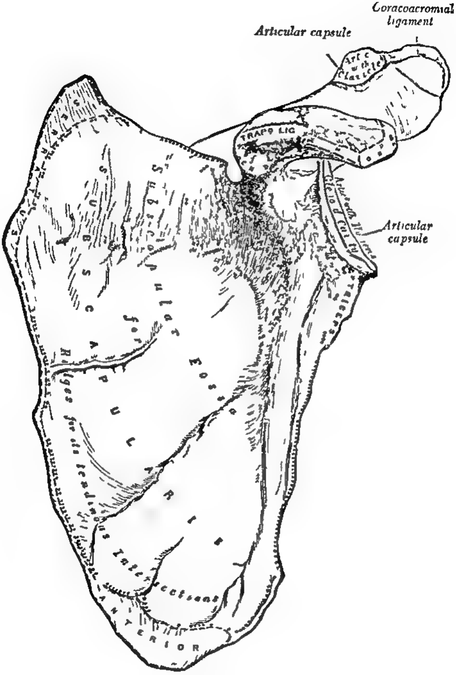


FIG 211 —Left scapula Costal surface

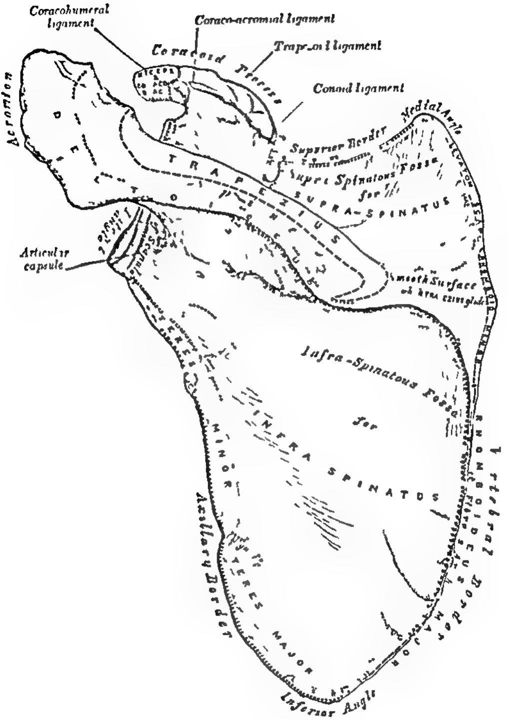


FIG 212 —Left scapula Dorsal surface

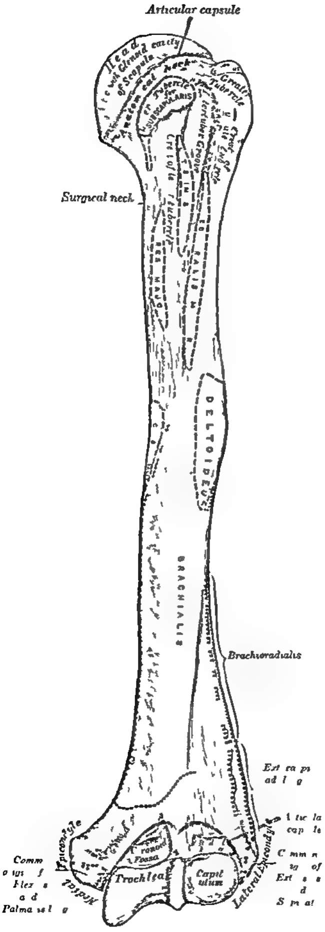


FIG 213 —Left humerus Anterior view

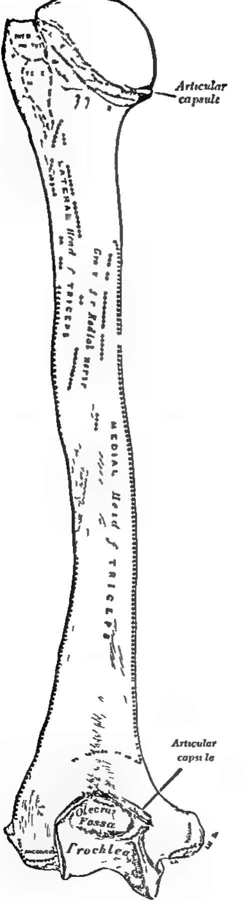


FIG 214 —Left humerus Posterior view

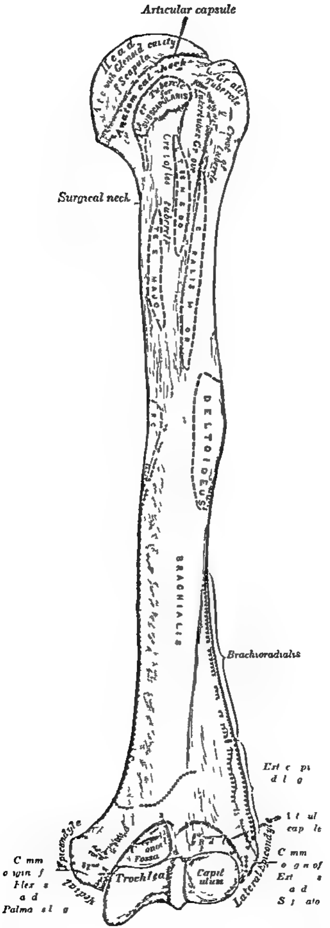


FIG 213 —Left humerus Anterior view

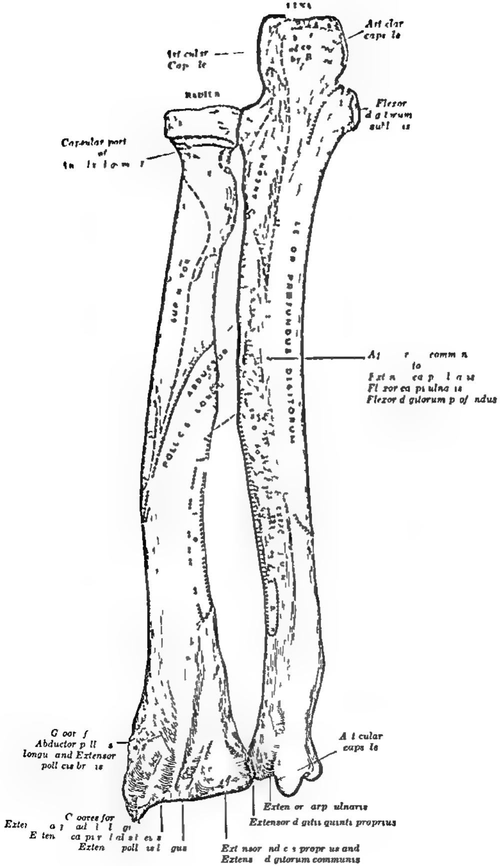


FIG 216 —Left radius and ulna Posterior aspect

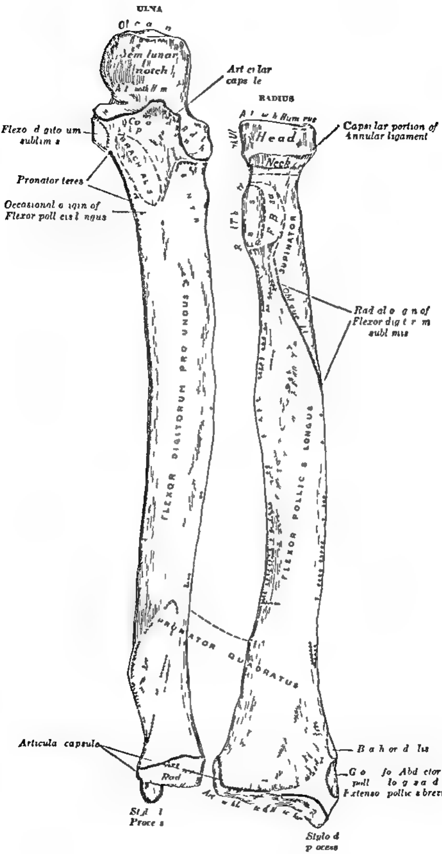


FIG 215 —Left ulna and radius Anterior aspect

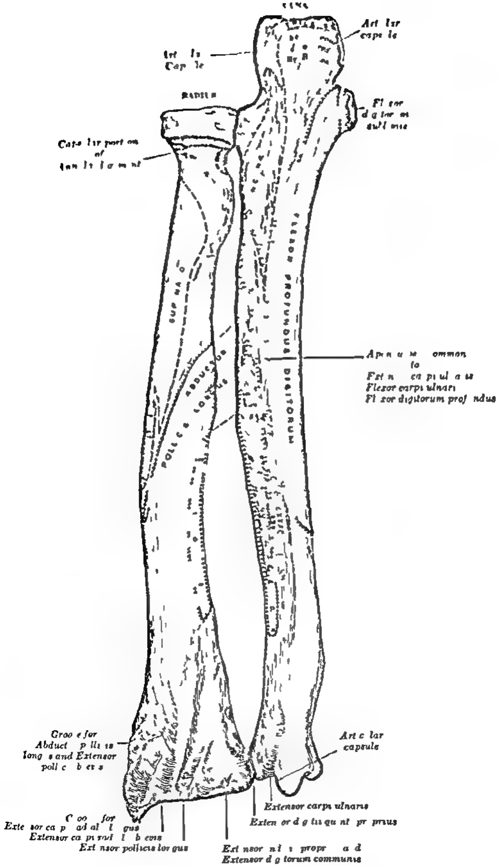


FIG 216 —Left radius and ulna Posterior aspect

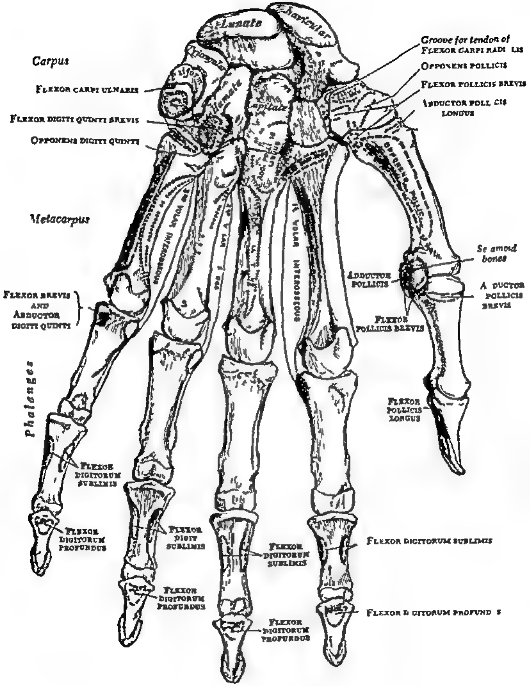


FIG 217 —Bones of left hand Volar surface

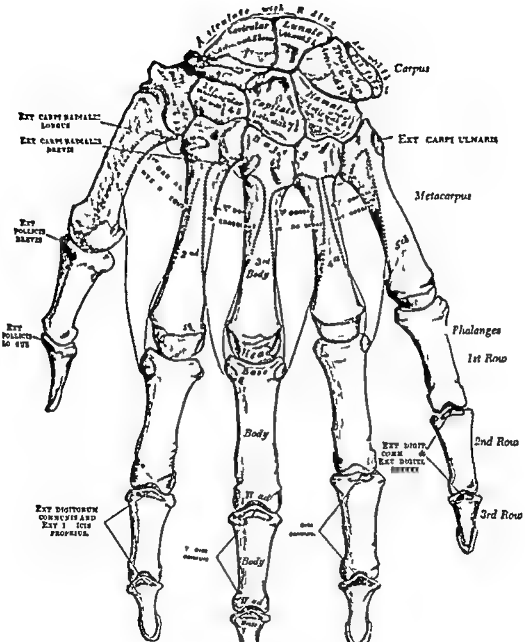


FIG 218 —Bones of left hand Dorsal surface

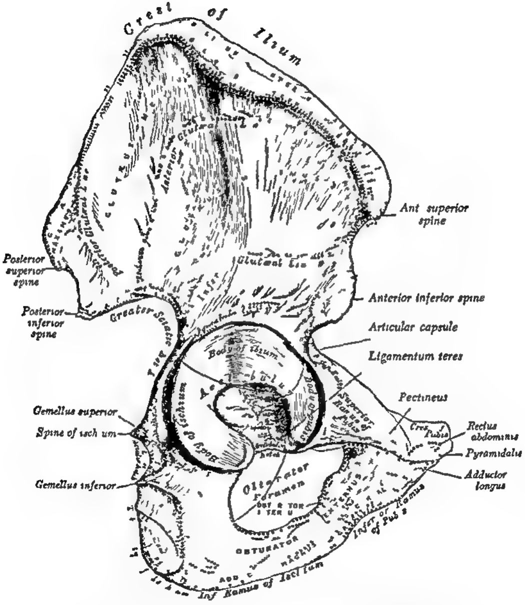


FIG 219 —Right ilium ischium and pubis External surface

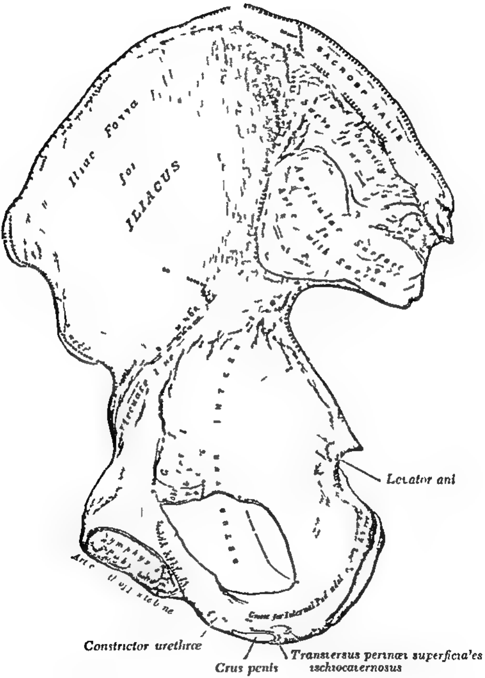


FIG 220 —Right ilium ischium and pubis Internal surface

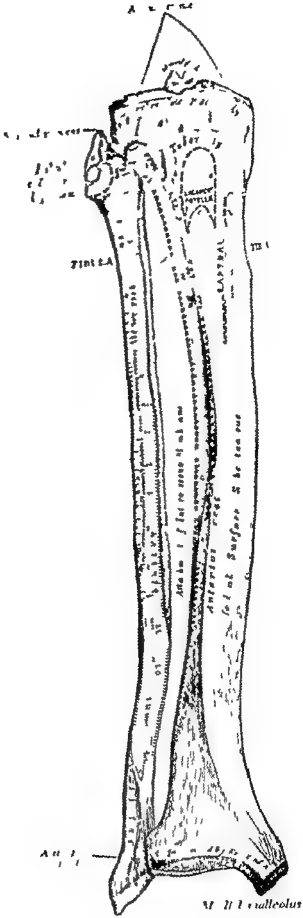
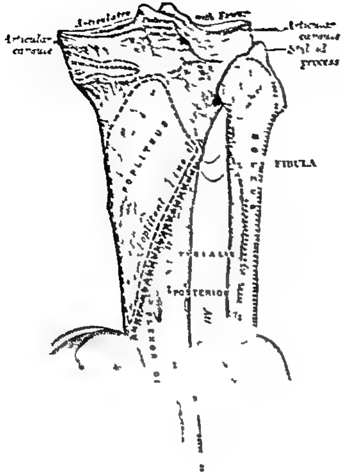


FIG 223 —Right fibula and tibia Anterior surface


FIBULA
POPLITEUS
TIBIALIS
POSTERIOR

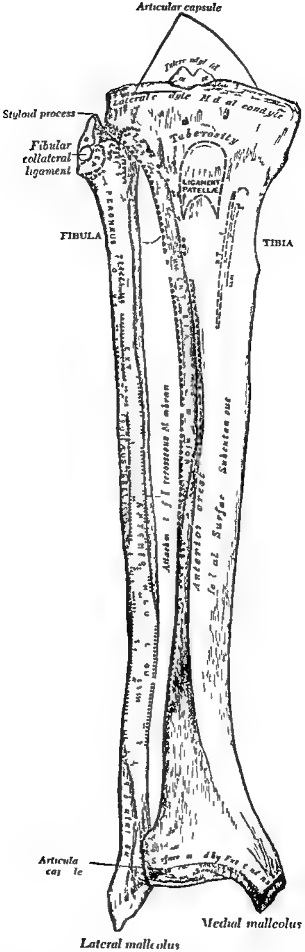
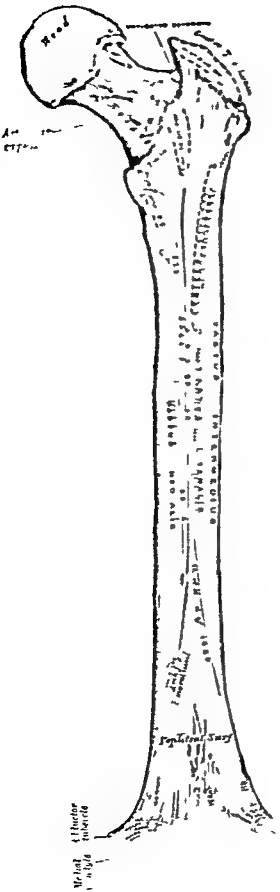


FIG 223 —Right fibula and tibia Anterior surf


Head
Popliteal Surf

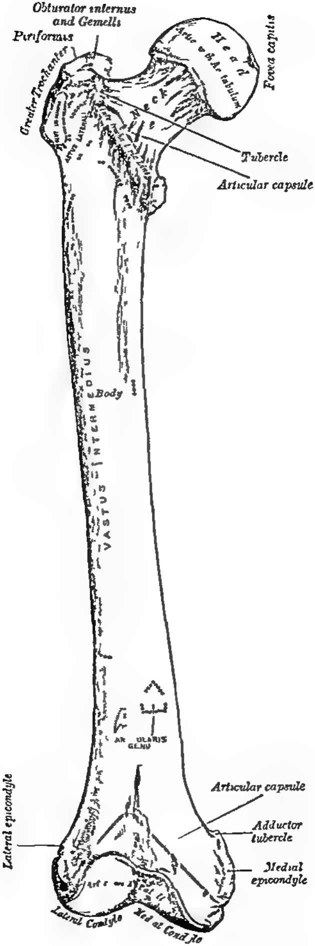


FIG 221 —Right femur Anterior surface

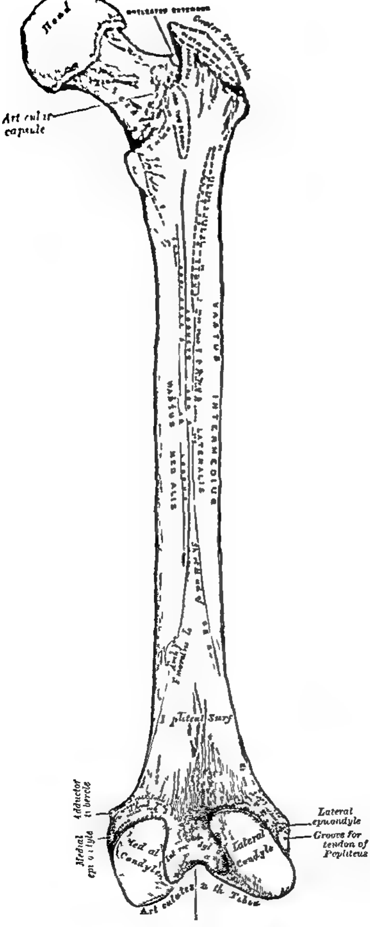


FIG 222 —Right femur Posterior surface

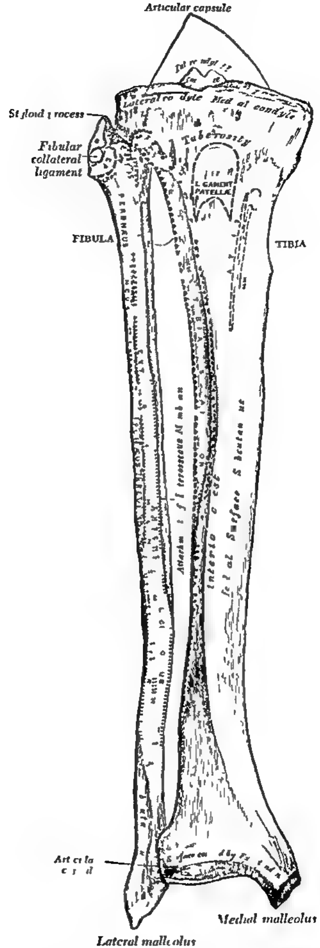


FIG 223 —Right fibula and tibia Anterior surface

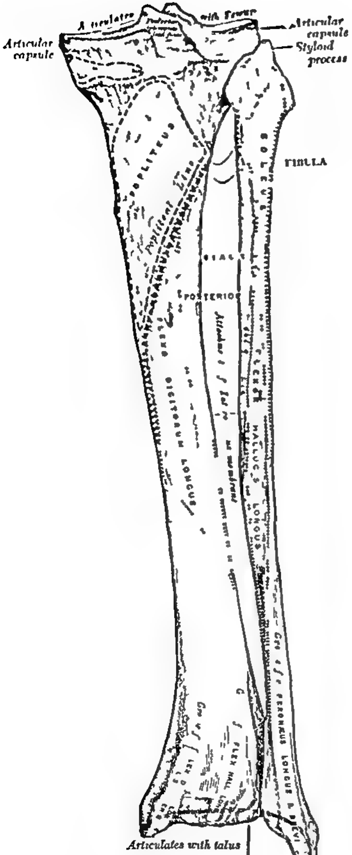


FIG 224 —Right tibia and fibula Posterior surface

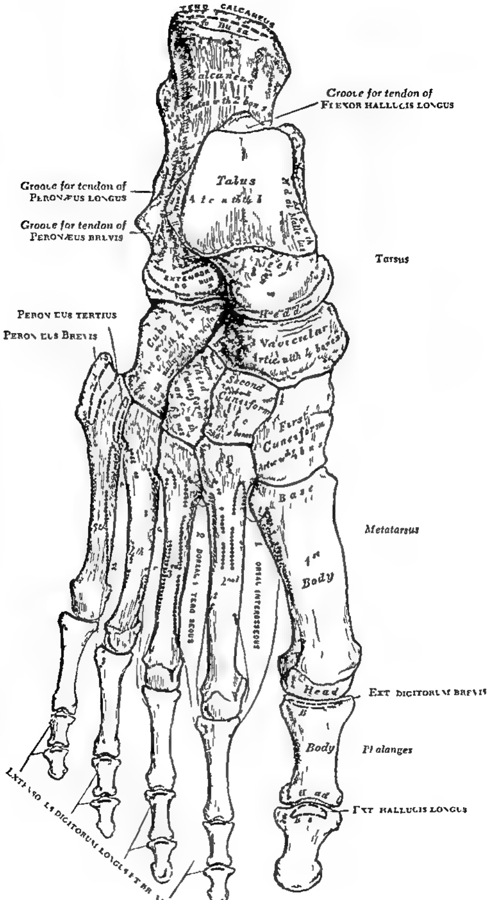


FIG 225 —Bones of right foot Dorsal surface

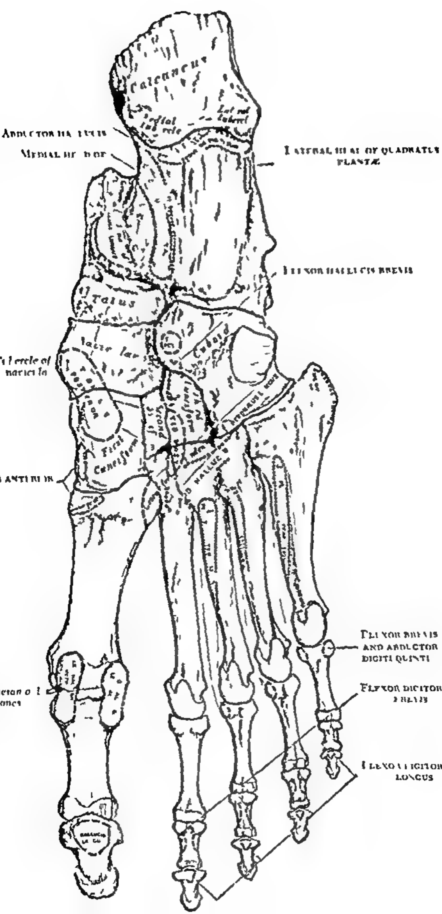


FIG 226 —Bones of right foot Plantar surface

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